Rudimentary and Elementary

TREATISE ON

STEAM AND LOCOMOTION;

BY JOHN SEWELL, L.E.

VOL. I.

With Illustrations.

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To James Fenton, Esqr.

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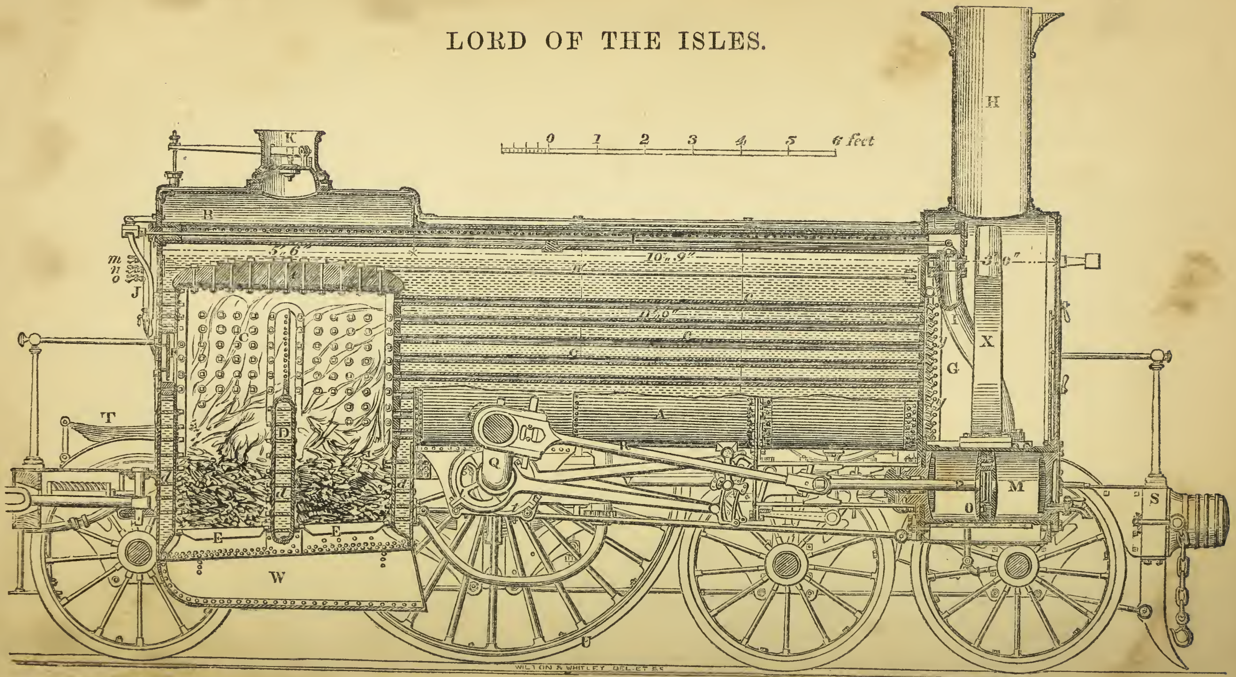
LORD OF THE ISLES.



ELEMENTARY TREATISE

ON

STEAM AND LOCOMOTION;

BASED ON THE PRINCIPLE OF

CONNECTING SCIENCE WITH PRACTICE,
IN A POPULAR FORM.

With Illustrations.

BY

JOHN SEWELL, L.E.

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PREFACE.

The increasing extension of steam-power leads to an extending desire to become conversant with its economical production and employment. True economy is however slowly realised by practice alone, as is testified by the history of many important inventions, as well as by that of the steam-engine; but when science and practice harmoniously co-operate, progress is greatly accelerated. In steam locomotion it is an every-day duty to generate and employ steam; but it requires the joint aid of both science and practice to decide whether these two distinct processes are or are not economically performed. In drawing inferences from observed facts, practice is powerfully assisted by a scientific knowledge of the natural agents it has to deal with, and the properties of their compounds. In steam locomotion the natural agents are water, fuel, heat, and metals. The compounds are combustion and steam. Science points out the composition of water, of fuel, and the heat-transmitting power of metals. It also acquaints us with the properties of steam, and the process of combustion. Practice observes facts corroborative or corrective of theories, and improves the mechanism, until, in the example of a locomotive engine, every pulsation of the escaping steam is evidence of the successful union of science and practice.

The importance of such union, and the absence of early scientific education in a very large portion of the community, have led us to give a popular digest of the properties of water, fuel, heat and steam, with remarks on combustion and the manufacture of coke, as essential preliminaries to either true locomotion or even domestic economy. This digest is accompanied by valuable classified tables of the mechanical, combustible, and chemical characteristics of 168 varieties of

British and Foreign coals, derived principally from the important researches conducted at the Museum of Practical Geology. This attempt to combine theory and practice is a plan strongly recommended by Sir H. De la Beche, Dr. Whewell, Dr. Lyon Playfair, and other eminent men of science, as necessary to progress; also in the excellent philosophical work on Mathematical Physics, written by John Herepath, Esq.

To promote such progress, and convey popular information on steam locomotion, is the design of this treatise, of which the first or theoretical part is now published. The second part, containing familiar descriptions of modern locomotive engines, will shortly follow. In a third part it is proposed to give a succinct historical outline of locomotive engines, with their connection with the eldest branch of the steam family noticed by Hero as "ancient" some 150 years before our era.

It is intended to add to the third volume a copious index that shall be useful for reference to the great variety of subjects treated of in the work.

To M. Morin, Director-General of the Conservatoire des Arts et Métiers, of Paris; Daniel Gooch, Esq., C. E.; Joseph Glynn, Esq., F. R. S.; Goldsworthy Gurney, Esq.; James Hann, Esq.; J. Herepath, Esq.; Seymour Clarke, Esq.; John Gray, Esq., M.D.; E. J. Dent, Esq.; J. Hackworth, Esq.; F. Trevethick, Esq.; A. Torry, Esq.; J. Deurance, Esq.; W. Buckle, Esq.; Hyde Clarke, Esq.; and other practical gentlemen who have placed information at the Author's service, he begs to return his grateful thanks.

There is much valuable knowledge floating amongst practical men, which would be useful if collected and arranged.

Information, therefore, on any point connected with the history or improvement, either of past or modern locomotives, from any one, will be duly acknowledged, as contributions to an accurate history of steam locomotion, that honour may be given to whom honour is due.

Dec. 1, 1851. JOHN SEWELL.

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A TREATISE

ON

STEAM AND LOCOMOTION.

SECTION I.

CHAPTER I.

STEAM.

STEAM is pure water expanded by heat into an invisible vapour. The first practical step is to obtain the water, and the next to apply the heat to produce steam power.

That a power such as this is, which displays some of its force in ordinary domestic operations, should have arrested the attention of early philosophers to its capabilities is as natural a sequence of the new form given to water by heat, as that the steam from a tea-kettle should have pointed one of Dickens's Christmas tales. Its employment in philosophical experiments, and also by the priests of early ages to maintain their ascendency over the minds of the people is matter of history, but the exact period of its first introduction appears to be unknown. The most ancient account of its performances now extant is a treatise published by Hero of Alexandria, about 150 years before our era, or nearly 2000 years ago. In this treatise he described amongst the inventions of others, some of his own (which will be described in their place), and these have gained him the honour of being regarded as the first inventor of the steam engine, and Egypt as the land of its origin.

To understand the nature of steam, it is desirable to possess a knowledge of its component parts. Familiar as are these component bodies, water and heat, yet each of them has formed the subject of elaborate researches, and each of them yet excites interest; the water, as to its composition, and the heat as to its nature.

Taking them in their order of forming steam, the following summary of the generally received opinions regarding them will, it is trusted, prove interesting.

Composition of Water.

This well-known fluid is the basis of the weight and materiality of steam.

In its ordinary state water is a fluid covering a very large portion of the globe, performing most important duties. It is not only abundant as a fluid, but, united with other bodies, it forms a large proportion of animal and vegetable matter, for analyists tell us that potatoes contain 75 per cent., turnips 90 per cent., a beef steak 80 per cent., and a man 75 per cent. of water. Chemically, they tell us that, a man of 10 stone would be made up of 105 lbs. of water, and 35 lbs. of carbon and nitrogen, and that $\frac{5}{6}$ths of his daily food is water.

It has been general since Watt's discovery of the composition of water to define it as consisting of one volume of oxygen and two volumes of hydrogen, or by weight, 1 part of hydrogen and 8 parts of oxygen, the specific gravity of the latter being 16 times that of the former.

It is usual to prove this theory of the composition of water by burning or exploding these two gases in a glass vessel, when water is deposited equal in weight to that of the decomposed gases. It has, however, been suggested that the force required to compress these gases into water must also find some electrical agent in them so as to produce their marked compression in volume. For water is nearly 30 times heavier

than oxygen, 478 times heavier than hydrogen, and 34 times heavier than air.

The discovery of the composition of water has been ascribed by some to Watt, and by others to Cavendish. Lord Brougham, in his Discourse on Natural Theology, states, "Having examined the evidence, I am convinced Watt was the first discoverer in point of time." This being regarded as one of the greatest discoveries of the age, was naturally a point of emulation amongst those having the least chance of gaining such honour, and it has by no mean authority been awarded to Watt.

Science, however, both in America and in Belgium, has again aroused attention to the decomposition of water, and to the various economical uses to whichit may be applied.

About twenty years ago, Macvicar, of St. Andrews, called attention to the particles, or atoms, constituting hydrogen as being of the simplest forms, and that water might either be all hydrogen, or partly oxygen, partly hydrogen, as the atoms were in a more or less divided state. He regarded the hydrogen atom as the elementary one, and that electrical affinity combined these atoms in a variety of ways, to form oxygen, water, or other substances. These views received little notice at the time, but they are now apparently confirmed by the reported discoveries of Mr. Payne, of America.

These discoveries, if fairly established, are of great importance, and merit a short description of this mode of decomposing water to obtain heat, light, and power.

According to Mr. Payne's experiments, water can be converted into hydrogen, or oxygen, without any appearance of the other gas, or both gases can be produced at once. This is effected by a magneto-electric machine, with two horseshoe magnets, about 12 inches long, placed horizontally on a frame, but the one 4 inches higher than the other. Between the ends of these magnets, two *helices* are set in rapid motion by a wheel. In the construction of the helices the greatly in-

creased power is said to be obtained. They are not formed of solid wire, as is usual, but of copper strips wound round spirally so as to form a hollow wire in which water can be confined. This wire is insulated by means of India rubber or gutta percha. Faraday has demonstrated that a small quantity of water will contain a vast quantity of electricity, so that it is inferred that as the water power of the helices is increased to induce or receive the electric current, so is the power increased to give it off.

The manner of applying the power so obtained is as follows:—In an open vessel of water is placed a common bell glass, reaching within 4 inches of the bottom of the vessel. The top of this glass is fitted with a brass cap for admitting the wires for connecting it with another jar of spirit of turpentine, when it is required for illumination. After passing through this cap of the first jar, the wires terminate in a cylindrical box $1\frac{1}{2}$ inches long by 1 inch diameter, perforated with small holes round the top part. In this box are the *electrodes* or points of connection of the poles, and here is the point of danger from the intensity of the force evolved by the helices.

The turpentine jar has also a cap fitted to it for connecting it with the water jar, and also with a gas burner.

It is stated that hydrogen only is produced by the action of the negative electricity, and oxygen only by positive electricity; but when both kinds of electricity are used, both oxygen and hydrogen are evolved. The interruption of the alternate current is said to be effected by immersing the broken ends of the wire in a glass of water, without being in contact, leaving the broken wire less active. For illumination the hydrogen is passed through the turpentine, when it becomes "catalized," and burns with great brilliancy.

From this it is inferred that hydrogen is a gas and negative electricity, and oxygen the same gas and positive electricity, and that water is, therefore, either all hydrogen, or all oxygen, or partly both, according to the electricity employed in decom-

posing it. The cost of production is said to be so small that either as a power or as a combustible it will exercise great economical influence.

The editor of the "Boston Chronotype," who appears to have seen the whole process gone through, states, "The power of the helices to the mechanical combination of the machine, is comparatively as the force of water in moving a large water wheel is to the force required to raise the water gate." He also distinctly warns experimenters to be guarded as to the power evolved in the electrode, lest it should prove uncontrollable with serious results, for each discharge of the helices produces a numerous crop of bubbles of gas in the water. These bubbles are a singular and important coincidence with the globules formed by ordinary heat in generating steam, which will be further noticed under that head.

Trials by our own electricians are said to have failed, yet M. Nollet, of Brussels, has just patented in England his improved plan and the use of the gases as a motive power similar to steam in the atmospheric engine.

Power of Water.

Simple as may be the appearance of water, it forms a most valuable part of creation, and in each of its characters, of a solid, as ice; of a fluid, as water; or of a vapour, as steam, it developes immense power. It is at its greatest density about 40° Fah. but does not become solid until 32°, when its expansive force is exhibited in the disintegration of rocks, bursting of pipes, or fracturing other bodies in which it may be confined, as practically tested in the following trials made in the Arsenal at Warsaw, in 1828-9, for the purpose of ascertaining the expansive force of water in a state of freezing.

For this purpose cast-iron howitzer shells, 6 in. 8 lines diameter, having a thickness of metal 1 in. 2 lines, and an orifice, or opening of 1 in. 2 lines diameter, were employed. One of these

shells having a capacity of 46·29 cubic in. was filled with water at 40° Fah. and with the orifice open exposed to the atmosphere at 21° Fah. In two hours a column of ice 2 in. 2 lines long was projected from the opening, which was the greatest effort made, and gave an expansive force of 2·31 cub. in. or about $\frac{1}{20}$th part of the whole volume, or 5 per cent.

A second shell was filled, and the orifice closed with a piece of wood driven into it. It was then exposed as before, when the plug was expelled, and ice occupied its place.

A third shell was filled, and the orifice closed with an iron screw, having through it a hole 3 lines diameter. After two hours' exposure the shell was burst into two unequal parts, the smaller being thrown 10 feet, and the larger part thrown 1 foot from the spot it was placed upon. The ice had formed only 6 lines thick, the remainder being still fluid. A fourth shell was filled, plugged, and exposed at 28° in a similar manner, with a hole of 6 lines diameter, and also burst in two parts, one of them being thrown a distance of 4 feet. The ice was 13 lines thick, the rest fluid. A fifth shell was filled, plugged up solidly, and exposed at 28°, when it burst as before, and the smallest piece was thrown a distance of one foot. The thickness of the ice was only 5 lines.

These will convey some definite idea of the expansive power of water in a freezing state, which is supposed to be derived from the re-arrangement of the crystalizing particles in angles of 60° or 120° to each other, requiring more space than when in a fluid state, and thus resisting confinement.

In giving motion to machinery, water, from its uniform action, has long been held in deserved repute. It has been attempted to be made the means of keeping up a regular power by a given quantity of water raised by a steam engine, and then giving motion to an overshot water wheel. The following table will show that the best constructed water wheels yet used do not exceed 80 per cent. of the full weight of water, consequently to employ steam power to raise another power,

and then to lose 20 per cent. of the power so raised was the reverse of economy, and has, of course, been abandoned.

Of the water employed on the different wheels the useful effect is for

The Undershot Wheel	from	27 to 33	per cent.
,, Breast	,, ,,	45 ,, 52	,,
,, Overshot	,, ,,	60 ,, 80	,,
,, Re-action or Turbine		56 ,, 78	,,

It may be explained that the undershot wheel is used when a fall is not obtainable, and the water only acts by its force against the float at the extremity of the arms. The breast wheel is employed where there is more fall, and the water enters the buckets, and acts by its weight. The overshot wheel is general where there is sufficient fall to carry the water over its top, and allow it to act on the opposite side, both by its force and weight. The turbine is of modern invention, where the water enters the arms of the wheel from a central tube, and issues by orifices at their extremities, but on opposite sides. The force of the issuing water being thus unbalanced, or flowing in one direction only, causes the arms to revolve in contrary directions. As now improved both in this country and on the Continent, these wheels are in considerable repute for economy of power and space. Gwyne's newly patented modification of the turbine and bucket wheel is said to generate 85 per cent. of the power employed. In all these wheels the weight of water is as its contents multiplied by its gravity of 10 lbs. each imperial gallon, but its force or pressure is as its height. Thus comparatively a column of water 34 ft. high, a column of air the entire height of the atmosphere, and a column of mercury 30 in. high are all equal in weight. That weight is nearly 14¾ lbs. avoirdupois.

The following table, by Fenwick, of the power of an overshot water wheel, a wind mill, and a steam engine, will be useful for reference:—

TABLE No. 1.

COMPARATIVE EFFECT OF MOTIVE POWERS.

WATER, acting on a 10-foot wheel, per min.	STEAM. Diameter of Cylinder.		HORSES, each 12 hours, at a rate of 2 miles per hour.	MEN, each 12 hours per day.	WIND. Radius of Sails.			POWER, = 1000 lbs. raised per minute.
	Old Class.	Improved Class.			Common.	Dutch.	Smeaton's.	
Lbs.	Inch.	Inch.	No.	No.	Feet.	Feet.	Feet.	Feet.
2,300	8	6·12	1	5	21·24	17·89	15·65	13
3,900	9·5	7·8	2	10	30·04	25·30	22·13	26
5,280	10·5	8·2	3	15	36·80	30·98	27·11	39
6,600	11·5	8·8	4	20	42·48	35·78	31·3	52
7,900	12·5	9·35	5	25	47·50	40·	35·	65
9,700	14·	10·55	6	30	52·03	43·82	38·34	78
11,700	15·4	11·75	7	35	56·90	47·33	41·41	91
13,500	16·8	12·8	8	40	60·09	50·60	44·27	104
14,550	17·3	13·6	9	45	63·73	53·66	46·96	117
15,840	18·5	14·2	10	50	67·17	56·57	49·50	130
17,400	19·4	14·8	11	55	70·46	59·33	51·91	143
19,000	20·2	15·2	12	60	73·59	61·97	54·22	156
21,000	21·	16·2	13	65	76·59	64·5	56·43	169
23,000	22·	17·	14	70	79·49	66·94	58·57	182
25,000	23·1	17·8	15	75	82·27	69·28	60·62	195
26,860	23·9	18·3	16	80	84·97	71·55	62·61	208
28,700	24·7	19·	17	85	87·07	73·32	64·16	221
30,550	25·5	19·6	18	90	90·13	75·90	67·41	234
32,400	26·2	20·1	19	95	92·60	77·98	68·23	247
34,260	27·	20·7	20	100	95·	80·	70·	260
37,500	28·5	22·2	22	110	99·64	83·9	73·42	286
40,000	29·8	23·	24	120	104·06	87·63	75·68	312
44,600	31·1	23·9	26	130	108·32	91·22	79·81	338
48,500	32·4	24·7	28	140	112·20	94·66	82·82	364
52,500	33·6	25·5	30	150	116·35	97·98	85·73	390

Forcing Power of Water.

Water forms a remarkable exception to the general law of expansion by heat, for it is more bulky when only 32° than when it is 8° hotter, or 40° temperature. Being then at its greatest density, and almost incompressible, it is made to develop its immense power in Bramah's hydraulic presses, whereby the strength of cables, anchors, iron, and other materials is tested, goods packed, and other operations performed requiring great force.

One of its most recent performances in this field was lifting the Conway and Britannia tubular bridges, up 100 ft. into their places. The weight of the largest tube being about 1800 tons, and one end lifted at a time, gave about 900 tons as the weight to be raised at once. This was done by a strong cast-iron cylinder, 11 in. thick, with a solid piston, or ram 20 in. in diameter and 6 ft. stroke, working through a water-tight stuffing box or gland, now to be seen in the Industrial Exhibition. Into this cylinder the water was forced through a half-inch pipe by a pump of $1\frac{1}{16}$ in. diameter worked by a 40-horse steam engine. The power would therefore be as the areas of the ram and pump were to each other, or as 1 to 355. The pressure on the ram would then be 900 tons, or

$$\frac{900 \times 2240 \text{ (lbs. water)}}{314{\cdot}16 \text{ (area of piston)}} = 6417 \text{ lbs. pressure for}$$

each square inch of the head of the ram.* The action may be thus explained: water is slowly forced into the cylinder by the pump, and being very nearly incompressible, as soon as the vacant space in the cylinder is filled, it gradually impels the ram outwards, with a force measured by the resistance against the external end of the ram, and limited by the strength of the cylinder and power of the pump to force in the water.

Weight and Measure of Water.

As a liquid, water is made the standard of comparison of the specific weight or gravities of other liquids and solids. At 55° fah. a cubic foot of water weighs 998·74 ounces avoidupois, but for facility in calculations it is generally taken as 1000 ounces, and the imperial gallon is fixed at 160 ounces, or 10 lbs. avoirdupois of distilled water. By weight a cubic foot of water is taken as $62\frac{1}{2}$ lbs., and by this data the cubic contents in feet of any water tank or boiler multiplied by $62\frac{1}{2}$ gives the weight of water in lbs. avoirdupois, and these

* For an interesting description of these bridges, see Rudimentary Treatise on Iron Girder Bridges.

lbs. divided by 10 give the number of gallons. Thus if the water space in a boiler be 60 cubic ft. it will contain 3750 lbs. or 375 gallons of water, for

$$60 \times 62{\cdot}5 = 3750 \text{ lbs. and } \frac{3750}{10} = 375 \text{ gallons.}$$

The standard fixed by Parliament for the Imperial gallon being 10 lbs. avoirdupois, at a temperature of 62 Fah. the following table gives the weight of a gallon of water at each degree of temperature from 32° to 80° :

TABLE No. 2.

WEIGHT OF A GALLON OF WATER AT VARIOUS TEMPERATURES.

Deg. Fah.	Lbs. Avoir.	Deg. Fah.	Lbs. Avoir.	Deg. Fah.	Lbs. Avoir.
80	9·9777	63	9·9989	47	10·0099
79	9·9792	62	10·0000	46	10·0102
78	9·9806	61	10·0010	45	10·0105
77	9·9820	60	10·0019	44	10·0107
76	9·9834	59	10·0027	43	10·0109
75	9·9848	58	10·0035	42	10·0111
74	9·9861	57	10·0043	41	10·0112
73	9·9874	56	10·0050	40	10·0113
72	9·9887	55	10·0057	39	10·0113
71	9·9900	54	10·0064	38	10·0113
70	9·9912	53	10·0070	37	10·0112
69	9·9924	52	10·0076	36	10·0111
68	9·9935	51	10·0082	35	10·0109
67	9·9946	50	10·0087	34	10·0107
66	9·9957	49	10·0091	33	10·0104
65	9·9968	48	10·0095	32	10·0101
64	9·9979				

This shows that from the point of greatest density (38° to 40°) it expands equally in both ways, becoming gradually

lighter per gallon. Sea water has its greatest density at the freezing point.

For calculating the quantities of water contained in either cylindrical or rectangular vessels, the following approximate exponents of the relative weights and measures of water at its ordinary temperature will be useful.

For Cylindrical Vessels or Boilers.

Water.

Cyl. in.		Diam. length.		Lbs. avr.		Imp. gal.
1	or	1	× 1 =	·02842	or	·00284
12	or	1	× 12 =	·341	or	·034
1728	or	1 cyl. ft.	=	49·1	or	4·91
2·282 cyl. ft.			=	1 cwt.	or	11·2
45·64 cyl. ft.			=	1 ton	or	224·
		352·97 cyl. in.	=	1 gal.		
		1·273 ,,	=	1 cubic in.		
		1· ,,	=	·7854 ,,		

To find the capacity of any other cylinder, multiply the square of its diameter by its length, and the product by the exponent of the unit of the feet or inches in which the dimensions may be taken. For elliptical vessels or boilers multiply the longest by the shortest diameter, and by the length for the capacity in cylindrical inches, and the product by the required exponent.

For concentric spaces add together the inner and outer diameters, and multiply the sum by the difference of these diameters, and by the length for the capacity in cylindrical inches, which being multiplied by the tabular exponent will give the required quantity.

Spherical Vessels.

	lbs. avr.	gal. imp.	
A globe of water 1 in. diam. =	·0189 or	·001888	or 1 spherical inch.
A globe of water 12 in. diam. =	32·75 or	3·263	or 1 spherical foot.

To find the capacity of any other sphere multiply the cube of its diameter by the required exponent of unity of the dimensions taken in feet or inches.

Rectangular and Cubical Vessels.

Water.

Cub. in.		Sq. length.		Lbs. avr.		Imp. gal.
1	or	1 × 1	=	·03617	or	·00361
12	or	1 × 12	=	·434	or	·0434
1728	or	1 cub. ft.	=	62·5	or	6·25
		1·8 cub. ft.	=	1 cwt.	or	11·2
		35·84 ,,	=	1 ton	or	224·
		277·274 cub. in.	=	1 imp. gal.		
		·1 ,,	=	1·273 cyl. in.		
		·7854 ,,	=	1· ,,		

The cubical contents of any other rectangular vessel may be found by multiplying the length, width and depth together, and their product by the requisite exponent.

Table No. 3.

AREAS OF THE SEGMENTS OF A CIRCLE,

Whose diameter is one, and divided into 1000 *equal or* 500 *parts for each half of the circle.*

Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.
·001	·000042	·022	·014322	·043	·011734	·064	·021168	·085	·032186
·002	·000119	·023	·004618	·044	·012142	·065	·021659	·086	·032745
·003	.000219	·024	·004921	·045	·012554	·066	·022154	·087	·033307
·004	·000337	·025	·005230	·046	·012971	·067	·022652	·088	·033872
·005	·000470	·026	·005546	·047	·013392	·068	·023154	·089	·034441
·006	·000618	·027	.005867	·048	·013818	·069	·023659	·090	·035011
·007	·000779	·028	·006194	·049	·014247	·070	·024168	·091	·035585
·008	·000951	·029	·006527	·050	·014681	·071	·024680	·092	·036162
·009	·001135	·030	·006865	·051	·015119	·072	·025195	·093	·036741
·010	·001329	·031	·007209	·052	·015561	·073	·025714	·094	·037323
·011	·001533	·032	·007558	·053	·016007	·074	·026236	·095	·037909
·012	·001746	·033	·007913	·054	·016457	·075	·026761	·096	·038496
·013	·001968	·034	·008273	·055	·016911	·076	·027289	.097	·039087
·014	·002199	·035	·008638	056	·017369	·077	·027821	·098	·039680
·015	·002438	·036	·009008	·057	·017831	·078	·028356	·099	·040276
·016	·002685	·037	·009383	·058	·018296	·079	·028894	·100	·040875
·017	·002940	·038	·009763	·059	·018766	·080	·029435	·101	·041476
·018	·003202	·039	·010148	·060	·019239	·081	·029979	·102	·042080
·019	·003471	·040	·010537	·061	·019716	·082	·030526	·103	·042687
·020	·003748	·041	·010931	·062	·020196	·083	·031076	·104	·043296
·021	·004031	·042	·011330	·063	·020680	·084	·031629	·105	·043908

Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.
·106	·044522	·154	·076746	·202	·113426	·250	·153546	·298	·196337
·107	·045139	·155	·077469	·203	·114230	·251	·154412	·299	·197252
·108	·045759	·156	·078194	·204	·115035	·252	·155280	·300	·198168
·109	·046381	·157	·078921	·205	·115842	·253	·156149	·301	·199085
·110	·047005	·158	·079649	·206	·116650	·254	·157019	·302	·200003
·111	·047632	·159	·080380	·207	·117460	·255	·157890	·303	·200922
·112	·048262	·160	·081112	·208	·118271	·256	·158762	·304	·201841
·113	·048894	·161	·081846	·209	·110083	·257	·159636	·305	·202761
·114	·049528	·162	·082582	·210	·119897	·258	·160510	·306	·203683
·115	·050165	·163	·083320	·211	·120712	·259	·161386	·307	·204605
·116	·040804	·164	·084059	·212	·121529	·260	·162263	·308	·205527
·117	·051446	·165	·084801	·213	·122347	·261	·163140	·309	·206451
·118	·052090	·166	·085544	·214	·123167	·262	·164019	·310	·207376
·119	·052736	·167	·086289	·215	·123988	·263	·164899	·311	·208301
·120	·053385	·168	·087036	·216	·124810	·264	·165780	·312	·209227
·121	·054036	·169	·087785	·217	·125634	·265	·166663	·313	·210154
·122	·054689	·170	·088535	·218	·126459	·266	·167546	·314	·211082
·123	·055345	·171	·089287	·219	·127285	·267	·168430	·315	·212011
·124	·056003	·172	·090041	·220	·128113	·268	·169315	·316	·212940
·125	·056663	·173	·090797	221	·128942	·269	·170202	·317	·213871
·126	·057326	·174	·091554	·222	·129773	·270	·171089	·318	·214802
·127	·057991	·175	·092313	·223	·130605	·271	·171971	·319	·215733
·128	·058658	·176	·093074	·224	·131438	·272	·172867	·320	·216666
·129	·059327	·177	·093836	·225	·132272	·273	·173758	·321	·217599
·130	·059999	·178	·094601	·226	·133108	·274	·174649	·322	·218533
·131	·060672	·179	·095366	·227	·133945	·275	·175542	·323	·219468
·132	·061348	·180	·096134	·228	·134784	·276	·176435	·324	·220404
·133	·062026	·181	·096903	·229	·135624	·277	·177330	·325	·221340
·134	·062707	·182	·097674	·230	·136465	·278	·178225	·326	·222277
·135	·063389	·183	·098447	·231	·137307	·279	·179122	·327	·223215
·136	·064074	·184	·099221	·232	·138150	·280	·180019	·328	·224154
·137	·064760	·185	·099997	·233	·138995	·281	·180918	·329	·225093
·138	·065449	·186	·100774	·234	·139841	·282	·181817	·330	·226033
·139	·066140	·187	·101553	·235	.140688	·283	·182718	·331	·226974
·140	·066833	·188	·102334	·236	·141537	·284	·183619	·332	·227915
·141	·067528	·189	·103116	·237	·142387	·285	·184521	·333	·228858
·142	·068225	·190	·103900	·238	·143238	·286	·185425	·334	·229801
·143	·068924	·191	·104685	·239	·144091	·287	·186329	·335	·230745
·144	·069625	·192	·105472	·240	·144944	·288	·187234	·336	·231689
·145	·070328	·193	·106261	·241	·145799	·289	·188140	·337	·232634
·146	·071033	·194	·107051	·242	·146655	·290	·189047	·338	·233580
·147	·071741	·195	·107842	·243	·147512	·291	·189955	·339	·234526
·148	·072450	·196	·108636	·244	·148371	·292	·190864	·340	·235473
·149	·073161	·197	·109430	·245	·149230	·293	·191775	·341	·236421
·150	·073874	·198	·110226	·246	·150091	·294	192684	·342	·237369
·151	·074589	·199	·111024	·247	·150953	·295	·193596	·343	·238318
·152	·075306	·200	·111823	·248	·151816	·296	·194509	·344	·239268
·153	·076026	·201	·112624	·249	·152680	·297	·195422	·345	·240218

Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.
·346	·241169	·377	·270951	·408	·301220	·439	·331850	·470	·362717
·347	·242121	·378	·271920	·409	·302203	·440	·332843	·471	·363715
·348	·243074	·379	·272890	·410	·303187	·441	·333836	·472	·364713
·349	·244026	380	·273861	·411	·304171	·442	·334829	·473	·365712
·350	·244980	·381	·274832	·412	·305155	·443	·335822	·474	·366710
·351	·245934	·382	·275803	·413	·306140	·444	·336816	·475	·367709
·352	·246889	·383	·276775	·414	·307125	·445	·337810	·476	·368708
·353	·247845	·384	·277748	·415	·308110	·446	·338804	·477	·369707
·354	·248801	·385	·278721	·416	·309095	·447	·339798	·478	·370706
·355	·249757	·386	·279694	·417	·310081	·448	·340793	·479	·371704
·356	·250715	·387	·280668	·418	·311068	·449	·341787	·480	·372704
·357	·251673	·388	·281642	·419	·312054	·450	·342782	·481	·373703
·358	·252631	·389	·282617	·420	·313041	·451	·343777	·482	·374702
·359	·253590	·390	·283592	·421	·314029	·452	·344772	·483	·375702
·360	·254550	·391	·284568	·422	·315016	·453	·345768	·484	·376702
·361	·255510	·392	·285544	·423	·316004	·454	·346764	·485	·377701
·362	·256471	·393	·286521	·424	·316992	·455	·347759	·486	·378701
·363	·257433	·394	·287498	·425	·317981	·456	·348755	·487	·379700
·364	·258395	·395	·288476	·426	·318970	·457	·349752	·488	·380700
·365	·259357	·396	·289453	·427	·319959	·458	·350748	·489	·381699
·366	·260320	·397	·290432	·428	·320948	·459	·351745	·490	·382699
·367	·261284	·398	·291411	·429	·321938	·460	·352742	·491	·383699
·368	·262248	·399	·292390	·430	·322928	·461	·353739	·492	·384699
·369	·263213	·400	·293369	·431	·323918	·462	·354736	·493	·385699
·370	·264178	·401	·294349	·432	·324909	·463	·355732	·494	·386699
·371	·265144	·402	·295330	·433	·325900	·464	·356730	·495	·387699
·372	·266111	·403	·296311	·434	·326892	·465	·357727	·496	·388699
·373	·267078	·404	·297292	·435	·327882	·466	·358725	·497	·389699
·374	·268045	·405	·298273	·436	·328874	·467	·359723	·498	·390699
·375	·269013	·406	·299255	·437	·329866	·468	·360721	.499	.391699
·376	·269982	·407	·300238	·438	·330858	·469	·361719	.500	·392699

PROBLEM,

To find the Area of a Segment of a Circle.

Rule.—Divide the height, or versed sine, by the diameter of the circle, and opposite the quotient in the column of heights.

Take out the area, in the column on the right hand, and multiply it by the square of the diameter, for the area of the segment.

Example,—Required the area of a segment of a circle,

whose height is 9 inches, and the diameter of the circle 58 inches.

$9 \div 58 = \cdot 155$ and opposite $\cdot 155 = \cdot 07747 \times 58^2 = 261 \cdot 5$ sq. in. $\times 1 \cdot 273 = 331$ cubic inches, as the required area.

In calculating the separate contents of a cylindrical boiler, segmental spaces require to be measured, and for this purpose the foregoing tabular area of 500 segments or one half of a circle whose diameter is 1, or unity, will be useful. The areas are in square measure, which requires to be multiplied by 1·273 for circular inches.

The following practical examples will show how part of these exponents may be usefully applied to ascertain very nearly the quantity of water which is in any boiler or tender, or other vessel.

EXAMPLE 1.—Taking the dimensions of the Lord of the Isles' locomotive boiler to be as under, required the quantity of water in tons and in gallons which would fill it to the water line 9 inches below the top of the cylindrical part of the boiler.

Dimensions.

CYLINDRICAL PART, 11 ft. long by 58 in. diameter, containing 303 tubes, each 2 in. external diameter, and 10 iron stay rods each $1\frac{1}{4}$ in. diameter. Steam space a segment of the top of this part whose height or versed sine is 9 in.

FIRE BOX PART, 71 in. wide, 66 in. long, and 63 in. mean depth,
less inside fire box, 64 ,, 60 ,, ,, 63 ,, ,,
leaving water spaces.

Front and back	71 in. wide,	63 in. deep,	and 3 in.	mean space.
Two sides, each	60 in. long,	63 in. ,,	and $3\frac{1}{2}$ in.	,, ,,
Top of fire box	69 in. wide,	9 in. ,,	and 66 in.	long.
Partition	63 in. ,,	51 in. ,,	and 4 in.	space.

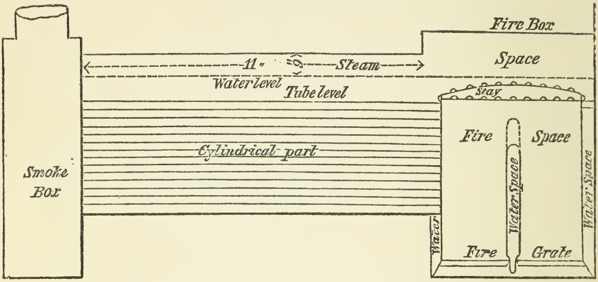
Less.

	"	"	"		Cir. in.
Fire door	21 ×	18 ×	3	tubes	= 1212 × 3,in. long.
12 stays	$1\frac{1}{2}$ ×	$6\frac{1}{2}$ ×	60,	10 stay rods	$1\frac{1}{4}$ diam. × 66 in. long.

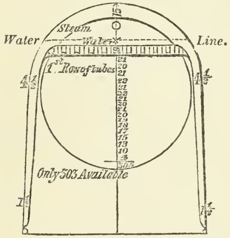
Steam space, a segment of the top of the fire box whose height or versed sine is 15 inches of a circle 71 inches diameter.

Boiler.

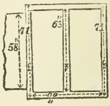
Longitudinal Section.



Transverse Section of Fire Box.



Plan of Fire Box.



These three diagrams will give an outline of the internal arrangement of the water, fire, and steam spaces in the Lord of the Isles' locomotive boiler.

Fig. No. 1 is a longitudinal section, showing the front and back water spaces between the outside shell of the boiler and inside fire-box. The transverse central water space which reaches up to the level of the fire door in the centre, and higher at the sides is also shown. The fire-box is thus divided

into two rectangular spaces, whose flat sides are strongly secured by numerous copper stays to the outside shell to resist the force of the steam. From the smallness of the diagrams these stays are not shown, but only one of the strong wrought-iron stays necessary to support the flat top of the fire-box, 303 tubes each, 11 ft. long, by 2 inches external diameter convey the heated gases from the fire to the chimney, usually placed on the top of the smoke box. The line of the water level shows the comparative depth of the sectional steam and water spaces, whilst the line of the tubes and top of the fire-box shows the heating space.

Fig. No. 2 is a transverse sectional view of the fire-box, showing the two side water spaces between the inside and outside boxes, which are also strongly secured together by copper stays. The complete circle shows the area of the cylindrical part of the boiler, and the larger circle the area of the fire-box outside shell. The water line shows the comparative steam space in each of these parts.

Fig. No. 3, is a plan of the fire-box, showing how the circulation of the water spaces is arranged, and which spaces communicate with the cylindrical part below the tubes, as shown in Fig. 1.

From these dimensions we have for the cylindrical parts:

		Cir. in.
Sectional area of boiler $= 58^2$		$= 3364$
	Cir. in.	
less tubular area of 303 tubes $\times 2^2 =$ . .	1212	
and segmental steam space,		
$= \frac{9}{58} = \cdot155 = \cdot07747$ (tab. num.) $\times 58^2 = 260$ sq. in. $\times 1{\cdot}273 =$	331	1543
Leaving a sectional water area of		1821

which multiplied by the length $= 1821 \times 132 = 240372$ cy. in.
The tubular space $= 1212$ area $\times 132$ length $= 159984$ cy. in.
The steam space $= 331$ area $\times 132$ length $= 43692$ cy. in.

For the fire box or rectangular parts we have

					Cub. in.
Front and back spaces	= 71 in. ×	63 in. deep ×	3 in. wide × 2	=	26838
Side spaces	= 60 in. ×	63 in. deep ×	$3\frac{1}{2}$ in. wide × 2	=	26460
Partition spaces	= 63 in. ×	51 in. deep ×	4 in. wide × 1	=	12852
Top of fire box	= 66 in. ×	9 in. deep ×	69 in. wide × 1	=	40986
					107136

Deduct for back tubes = 1212 cub. in. × 3 × ·7854	= 2856		
For front fire door = 21 × 18 × 13	= 1134		
For stays of sides, ends, and partitions, $\frac{1}{16}$ of space	= 4134		
For top of box stays $\frac{1}{5}$ of water space	= 8193	=	16317
			90819

Or by taking the space included within the outside fire box, and deducting the inside one, thus,

Outside box = 71 wide × 66 long × 63 deep	= 295218
Less inside box = 64 wide × 60 long × 63 deep	= 241920
	53298
Add partition and top as above	= 53838
	107136
Less deductions as above	16317
Total water space round fire box	= 90819

Steam space $=\frac{15}{71}=\cdot 211=\cdot 120713$ (tab. num.) $\times 71^2=609$ sq. in. area, and 609×66 length $=40014$ sq. in. steam space on top of fire box.

Summary.

Steam Space.

	Cub. in.	Cy. in.	or	Cub. in.
Cylindrical part =		43692 × ·7854		=34315
Fire box part =	40014 × 1·273	=50938 ×		=40014
Total steam space		94630	or	74329

Compared with the capacity of the cylinders

$$=18 \text{ in. diameter by } 24 \text{ in. stroke} = 18^2 \times 24 = \frac{94630}{7776} = 12\cdot 17$$

times the capacity of 1 cylinder, or 6 times the capacity of the two cylinders.

Water Space.

	Cub. in.	Cy. in.	or	Cub. in.
Cylindrical part =		240372 × ·7854	=	188788
Fire box part =	90819 × 1·273 =	115612	=	90819
	Total water space =	355984	or	279607.

$$\overset{\text{Cyl. in.}}{\text{And } 355984} \times \overset{\text{Lbs.}}{\cdot 02842} = \overset{\text{Lbs. av.}}{\frac{10117}{2240}} = 4{\cdot}516 \text{ tons, or } \overset{\text{t.}}{4}\ \overset{\text{c.}}{10}\ \overset{\text{q.}}{1}\ \overset{\text{lb.}}{7} \quad \text{Gals. imp.}$$

and 355984 × ·00284 = 1011·7 gallons of water.

And by cubic measure,

$$\overset{\text{Cub. in.}}{279607} \times \overset{\text{Lbs.}}{\cdot 03617} = \overset{\text{Lbs. av.}}{\frac{10113}{2240}} = 4{\cdot}514, \text{ or } \overset{\text{t.}}{4}\ \overset{\text{c.}}{10}\ \overset{\text{q.}}{1}\ \overset{\text{lb.}}{3}$$

and 279607 × ·00361 = 1011·3 gallons,

being a difference of 4 lb. on the whole quantity, arising from the exponents being approximate and not strictly correct, but sufficiently near for practical purposes.

Heating Space.

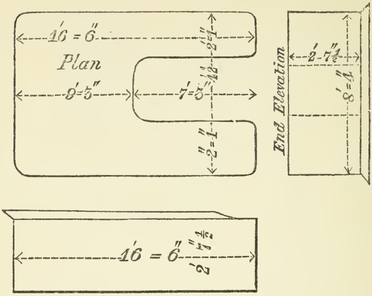
	Cub. in.	Cy. in.		Cub. in.
Tubular space =		159984 × ·7854	=	125651
Fire box =	241920 × 1·273 =	307964	=	241920
	Total heating space =	467948	or	367571.

Tabular Abstract of Boiler Contents.

		Cy. in.		Cub. in.	Ratio.	Per cent.
Steam space	=	94630	or	74329	1	10·3
Water space	=	355984	or	279607	3·73	38·75
Heating space	=	467948	or	367571	4·94	50·95.

Example 2.—Taking the dimensions of the tender water tank of the Lord of the Isles, locomotive engine, as under, required the quantity of water it will contain in lbs., in tons, and in gallons?

Tender Tank.



Length, 16′ 6″; width, 8′ 4″; depth, 2′ 7½″; less coke space, 7′ 3″ long, and 4′ 2″ wide and 2′ 7½″ deep.

	Cub. In.		Cub. Ft.
$178'' \times 100'' \times 31{\cdot}5'' =$	523700	$\div 1728 =$	360·9
less $87'' \times 50'' \times 31{\cdot}5'' =$	137025	$\div 1728 =$	79·3
	486675		281·6.

Cub. In. Lb.
and $486675 \times {\cdot}03617 = 17603$ lbs.
which divided by $2240 = 7$ tons, 17 cwt., 0 qr., 18 lbs.
for gallons $486675 \times {\cdot}00361 = 1760$ gallons,
or $281{\cdot}6$ cube ft. $\times 6{\cdot}25 = 1760$ gallons.

Abstract of Tender Contents.

	Cub. In.	Ratio.	Per cent.
Coke space	137025	1	18
Water space	623700	4·55	82.

Impurities of Water.

Since nothing but pure water is converted into pure steam, and the impurities of water are either deposited on the boiler, or, by the action of chemical agents, partly carried away in the

steam, to the detriment of slide-valves, and pistons; the following table will convey an idea of the impurities in well, river, and canal water.

All the London waters are from Professor Brande's Report. The New Swindon water is by Dr. Herapath, the eminent chemist, of Bristol.

Table No. 4.

IMPURITIES IN ONE GALLON OF WATER.

(70,000 grains = 1 imperial gallon.)

		Grains.		Per cent.
Thames at Greenwich		27·9	Average, 23·2 or ·0033.	·00398
,, London Bridge		28·		·004
,, Westminster		24·4		·0035
,, Brentford		19·2		·00274
,, Twickenham		22·4		·0032
,, Teddington		17·4		·0025
New River		19·2		·002
Colne		21·3		·00304
Lea		23·7		·00338
Ravensborne, at Deptford		20·		·00285
Combe and Delafield's Well,	deep	56·8		·0081
Apothecaries' Hall, Blackfriars	,,	45·		·00643
Notting Hill	,,	60·6		·00865
Royal Mint	,,	37·8		·0054
Hampstead Water Works	,,	40·		·00571
Berkeley Square	,,	60·		·00857
Tilbury Fort	,,	75·		·01071
Goding's Brewery	,,	50·		·00714
,,	shallow	110·		·01571
More's Brewery, Old Street	deep	38·9		·005557
,,	shallow	110·		·0157
Trafalgar Square fountains	deep	68·9		·00984
St. Paul's Churchyard	,,	75·		·01071

	Grains.	Per cent.
Bream's Buildings	115·	·01643
St. Giles, Holborn	105·	·015
St. Martin's, Charing Cross	95·	·01357
Postern Row, Tower	98·	·014
Artesian Well at Grenelle, Paris	9·86	·
New Swindon Canal, filtered	32·16	·00014

Of these a detailed analysis of the Royal Mint water, by Professor Brande, and of the New Swindon filtered canal water, by W. Herapath, Esq., of Bristol, will show the nature of these impurities.

In one gallon of water from the Royal Mint well there were—

Proximate saline components.	*Grains.*
Chloride of sodium	10·53
Sulphate of soda	13·14
Carbonate of soda	8·63
,, of lime	3·5
,, of magnesia	1·5
Silicia	0·5
Organic matter	Traces of.
Phosphoric acid	Traces of.
Iron	Traces of.

Substances in the water.	*Grains.*
Sulphuric acid	7·44
Chlorine	6·31
Carbonic acid (after boiling)	5·84
Silicia	0·50
Sodium combined with chlorine	4·22
Soda combined with sulphuric and carbonic acid	10·87
Lime	1·96
Magnesia	0·71
Organic matter	Traces of.
Phosphoric acid	Traces of.
Iron	Traces of.

In one gallon of New Swindon water there were—

	Grains in a gallon.
Chloride of magnesium (bittern)	·464
Sulphate of ,, (Epsom salts)	·048
Sulphate of soda (glauber salts)	5·744
Chloride of sodium (common salt)	2·736
Carbonate of lime (chalk)	12·16
Sulphate of lime (gypsum)	10·4
Organic matter (vegetable extract)	·608
	32·16

This water averages 20 grains of hardness, as it is called, which is more than the average of the London or Bristol

spring waters, which run from 12 to 16 grains. By boiling the water is reduced to 12 grains hardness.

These analyses of water indicate that locality has much to do with its comparative purity, and that in London, the shallow wells above the chalk, or about 200 to 220 feet deep, are more impure than those deep wells which draw their supplies below the chalk, or about 400 to 426 feet deep, as at the Royal Mint.

By knowing the particular impurities in any particular water, the practical engineer can decide with confidence whether it is or is not desirable to employ any chemical agent, such as oxalic acid, carbonate of potash, or soda, to precipitate, or nitric, muriatic, or acetic acid, to hold in solution and pass through with the steam some one of these impurities.

If only one agent, such as muriate of ammonia, be used, which thus holds in solution one of the impurities, say carbonate of lime, whilst the others, such as the sulphate of lime, are deposited by boiling; then it may even be more than doubtful if there be any present gain, and scarcely doubtful as to future injury to the rubbing surfaces and to the boiler itself, whilst the presence of any foreign body in the steam necessarily impairs its efficacy.

The effect of acids on iron is well known, and notwithstanding their dilution when used in boilers, they still appear to exercise injurious effects on particular makes of iron. In some locomotive boilers where muriate of ammonia has been employed, the internal surface of the part below the tubes was so deeply oxydized in numerous spots as to render it necessary to replace the plates to prevent accidents. In other boilers this effect is not so apparent. This difference is probably owing to the quality of the iron, or to the greater or lesser quantity of oxygen or other bodies it contains, having more or less affinity for acids, as both boilers were supplied with the same water. Similar results are observed from the action of the fire upon copper fire boxes, where one fire box will last much longer than another. The advocates of these

chemical agents deny their injurious action, but the accumulating evidence of observed destruction of tender tanks and boilers is a strong presumption that they cannot be used safely with every sort of iron, even if their employment were otherwise beneficial. Dr. Davies's analysis of locomotive deposits shows that they contain carbonate and sulphate of lime with a little magnesia, protoxide of iron, silicia and carbonaceous matter; and one about one tenth of an inch thick had formed during a run of 436 miles, and the consumption of 10,900 gallons of water.

*Hard and Soft Water for Domestic Use.**

Since water for domestic use is still more important to the public generally, the following remarks on its household properties will usefully conclude this chapter.

"The popular expressions *hard* and *soft* water really give little information concerning the wholesomeness or character of a particular water, and its adaptation for drinking or culinary or even washing purposes. Water may be 'soft,' free from organic impurity, but, owing to the presence of a large quantity of mineral matter, be quite unfitted for drinking, cooking, or even for washing. To give a practical illustration: the water supplying the Trafalgar Square fountains, and which is lifted from a well sunk into the chalk formation beneath the London clay, the bottom of which is about 350 feet below the level of the sea, is a 'soft' water about $5\frac{1}{2}°$ of hardness; but this water contains, according to the analysis of Mr. Brande and the Royal College of Chemistry, from 66 to 79 grains of mineral matter per gallon, from 60 to 72 grains of which are common salt and soda: water of this description is unfitted for drinking or making tea, and some other culinary operations, because the soda contained in it, when habitually used, acts medicinally on the kidneys; and

* S. C. Homersham, on the Supply of Water to the Metropolis. J. Weale, London.

it is unfitted for washing, because the effect of soda, if used for washing clothes, tends to discolour white cotton, flannel, or linen, and to spoil the colours of certain prints; it is also unfitted for warm baths, because the soda is apt to form a soap with the oily matter which exudes from the pores of the skin, and therefore causes it to become rough and chap.

"On the other hand, water may be 'soft' from the almost entire absence of mineral matter in solution; water of this description, from only 1° to 2° of hardness, may be found in streams fed from the rain falling upon the primitive geological formations. I have had water analyzed that was collected from streams fed by the rain falling upon the millstone-grit formation containing only $2\frac{1}{2}$ grains of mineral matter per gallon, and only $1\frac{1}{10}$th degree of hardness, and yet the use of this water for most purposes is avoided by the inhabitants living near these streams, because a large portion of the ground draining into them is covered with peat, which, being taken into solution, and especially in summer weather, so completely contaminates the water with organic matter, that it is unfitted for drinking; for, when so used, it produces sickness and diarrhæa. These streams, especially after heavy rains in the summer time, are discoloured with peat, and if used for washing, stain the coarsest linen and dim the bright colours of printed goods. This water is also bad for making tea, and spring water of a somewhat *harder* character (about 4° of hardness) is used in preference for this purpose; because, as the inhabitants express it, such very soft water draws out the wood of the tea, and spoils the flavour.

"It may be noted that M. Soyer states as the result of his experiment upon tea-making, that 'the softest or distilled water had an extraordinary power in obtaining a quick extract; *the result showed perhaps too high a power, for it draws out the woody flavour.*' It is some years since my attention was first practically drawn to the fact that water might be too soft

for the making of tea, and M. Soyer's evidence accords with popular experience in this respect.

"It may not be out of place to mention here that carbonate of soda, when added to a solution of tea, deepens the colour of the tea, without either improving the flavour or the strength; any one may prove this by pouring out a cup of tea and separating it from the grouts; if a small quantity of carbonate of soda be added to such a solution, the colour will be sensibly deepened, although it is quite evident that the strength of the tea is no greater after the addition of the soda than before. This fact may account for M. Soyer stating, that the water procured from the deep well of the Reform Club and Trafalgar Square fountains (both of which waters contain a quantity of carbonate of soda) ranks number one for tea-making; M. Soyer being doubtless misled by the *colour* of the infusion. His taste, being habituated to a water containing soda, would not be offended by the taste of this alkali.

"As we see, then, water may be 'soft' and free from organic matter, and yet, from the presence of a large quantity of alkaline salts, be unfitted for nearly all domestic uses. Water may also be 'soft' from the almost entire absence of salts, and yet from its high extractive power be unfitted for tea-making; while such water, especially in summer, when collected from the drainage of land covered with peat, or even vegetation of any kind, takes greedily in solution organic matter, which renders it unwholesome for drinking, and when discoloured with peat, quite unfitted for washing purposes.

"It is only when 'soft' water is free from alkaline salts, and devoid of organic matter in solution, that it can be considered as fitted for domestic purposes. Spring water issuing from the millstone grit, and other primitive formations, is often of this character; but the soft surface water collected in reservoirs, and used to supply Preston, Bury, Ashton, and other towns in Lancashire, is not good drinking water, owing to its containing, in the summer, organic matter; and it is a pity,

that when Dr. Sutherland was directed to make his 'local investigations' in Scotland and Lancashire, he was not instructed to inquire particularly into the amount of organic matter contained during autumn and summer weather in the 'soft' water collected in reservoirs for the use of town populations; had he done so, he would have discovered, what is well known to all practically acquainted with the subject, that the great bulk of such waters, at these seasons, is impregnated with organic impurities.

"The term *hard* water is equally indefinite as *soft* water. 'Hard' water may be 'hard' from holding in solution (as explained in the body of the Report) a certain amount of either lime salts or magnesian salts; and the character of a lime salt or magnesian salt again varies according as it may be combined with carbonic acid on the one hand, sulphuric acid, nitric acid, or any other acid, on the other hand. The quality and adaptation of a 'hard' water for domestic purposes is very different, according as it may be 'hard' from the presence of magnesia or lime, or of both these salts; so that it is only by knowing the amount and character of the mineral matter from which a water derives its 'hardness' that its wholesomeness or unwholesomeness, and its adaptation for domestic purposes, can be predicted.

"Again: 'hard' water may be contaminated, especially when warm, with excremental or organic matter in solution, although it is not so rapidly poisoned with these impurities as 'soft' water when free from alkaline salts."

CHAPTER II.

HEAT.

This widely-diffused body has led to much learned discussion on its nature, without arriving at any definite result. Its effects are apparent to all, but its nature is yet conjectural.

Its measurable quantity is comparatively ascertained by an instrument called a *thermometer,* and the quantity indicated on a scale of equal parts is designated its *temperature.*

The general effect of heat upon all bodies is to increase their bulk in some unascertained ratio to their density and molecular formation, excepting those bodies which diminish in volume, by heat evaporating the water they contain, such as newly-cut peat or clay.

Solids expand least, fluids next, and gases most by equal increments of heat. As compared with each other, neither solids nor fluids of the same class expand equally, a fact which has hitherto prevented any general law being defined for the rate of expansion of each class. Usually, though not always, the lighter bodies expand more than the heavier ones, as alcohol expands more than water, and water more than mercury.

Platinum, gold, silver, and zinc follow the general law, but copper, iron, and marble form exceptions.

The following Table, No. 5, shows the lineal expansion of solid bodies, from 32° to 212° by different experimenters.

In such delicate experiments uniformity of results is not to be expected, yet the averages may be taken as given in Table No. 6.

Table No. 5.

LINEAR EXPANSION OF SOLIDS AT 212° TAKING THE LENGTH OF THE BAR. AT 32° FAHR. AS 1 FOOT.

Name.	Experimenter.	Length at 212°. Feet.
Glass tube	Smeaton . . .	1·00083333
Ditto	Roy	1·00077615
Ditto	Deluc's mean . .	1·00082800
Ditto	Dulong and Petit . .	1·00086130
Ditto	Lavoisier and Laplace .	1·00081166
Plate glass	Ditto	1·00089089
Ditto crown glass . .	Ditto	1·00087572
Ditto	Ditto	1·00089760
Ditto	Ditto	1·00091751

Name.	Expermenter.	Length at 212°. Feet.
Glass rod	Roy	1·00080787
Platina purified . .	Roy, as glass . .	1·000857
Platina	Borda	1·00085655
Ditto	Dulong and Petit . .	1·00088420
Ditto.	Troughton . . .	1·00099180
Ditto and glass . . .	Berthoud . . .	1·00110000
Palladium	Wollaston . . .	1·00100000
Antimony	Smeaton . . .	1·00108300
Cast-iron prism . . .	Roy	1·00110940
Cast-iron	Lavoisier, by Dr. Young .	1·00111111
Steel	Troughton . . .	1·00118990
Ditto rod	Roy	1·00114470
Blistered steel . . .	Phil. Trans. 1795, p. 428 .	1·00112500
Ditto	Smeaton . . .	1·00107875
Steel not tempered . . .	Lavoisier and Laplace .	1·00107956
Ditto	Ditto	1·00107956
Ditto tempered yellow . .	Ditto	1·00136900
Ditto	Ditto	1·00138600
Ditto at a higher rate . .	Ditto	1·00123956
Steel	Troughton . . .	1·00118980
Hard steel	Smeaton	1·00122500
Annealed steel . . .	Musschenbröck . .	1·00122000
Tempered steel . . .	Ditto	1·00137000
Iron	Borda	1·00115600
Ditto	Smeaton	1·00125800
Soft iron forged . . .	Lavoisier and Laplace .	1·00122045
Round iron, wire drawn . .	Ditto	1·00123504
Iron wire	Troughton . . .	1·00144010
Iron	Dulong and Petit . .	1·00118203
Bismuth	Smeaton . . .	1·00139200
Annealed gold . . .	Musschenbröck . .	1·00146000
Gold	Ellicot, by comparison .	1·00150000
Ditto, procured by parting .	Lavoisier and Laplace .	1·00146606
Ditto, Paris standard . .	Ditto	1·00155155
Ditto, pure hammered . .	Ditto	1·001514
Ditto, ditto, annealed	Ditto	1·00151361
Copper	Musschenbröck . .	1·00191080
Ditto	Lavoisier and Laplace .	1·00172244
Ditto	Ditto	1·00171222
Ditto	Troughton . . .	1·00191880
Ditto	Dulong and Petit . .	1·00171821
Brass	Borda	1·00178300
Ditto	Lavoisier and Laplace .	1·00186671
Ditto	Ditto	1·00188971
Brass scale, supposed from Hamburgh . . .	Roy	1·00185540
Cast brass	Smeaton	1·00187500

Name.	Experimenter.	Length at 212°. Feet.
English plate brass, in form	Roy	1·00189280
Ditto, in a trough form	Ditto	1·00189490
Brass	Troughton	1·00191880
Ditto wire	Smeaton	1·00193000
Brass	Musschenbröck	1·00216000
Copper 8, tin 1	Smeaton	1·00181700
Silver	Herbert	1·00189000
Ditto	Ellicot, by comparison	1·00210000
Silver	Musschenbröck	1·00212000
Ditto of cupel	Lavoisier and Laplace	1·00190974
Ditto, Paris standard	Ditto	1·00190868
Silver	Troughton	1·00208260
Brass 16, tin 1	Smeaton	1·00190800
Speculum metal	Ditto	1·00193340
Spelter solder; brass 2, zinc 1	Ditto	1·00205800
Malacca tin	Lavoisier and Laplace	1·00193765
Tin from Falmouth	Ditto	1·00217298
Fine pewter	Smeaton	1·00228300
Grain tin	Ditto	1·00248300
Tin	Musschenbröck	1·00284000
Soft solder; lead 2, tin 1	Smeaton	1·00250800
Zinc 8, tin 1, a little hammered	Ditto	1·00269200
Lead	Lavoisier and Laplace	1·00284836
Ditto	Smeaton	1·00286700
Zinc	Ditto	1·00294200
Ditto, hammered out half-inch per foot	Ditto	1·00301100
Glass, from 32° to 212°	Dulong and Petit	1·00086130
Ditto, from 212° to 392°	Ditto	1·00091827
Ditto, from 392° to 572°	Ditto	1·000101114

The linear expansion multiplied by three gives the *total* expansion nearly. Thus for iron it would be 1 in 271, and for lead 1 in 117 to be considered in buildings; or, as in the instance of Bow Church spire, it may endanger the structure. The contracting power of expanded iron is usefully employed in various ways, and was the means used to draw the walls of the Museum of Arts in Paris from an inclining to a vertical position. The strain on many parts of locomotive engines from the unequal temperature and expansion of copper, brass, and iron will be readily calculated by the following averages which divided by three give the *ratio* of increased bulk.

Table No. 6.

AVERAGES OF A FEW OF THE PRINCIPAL SOLIDS.

Averages of the Linear Expansion of Metals from 32° to 212°.

Name.	Increased length at 212°.		Name.	Increased length at 212°.	
Zinc sheet,	1 part in . .	340	Iron,	1 part in . .	812
Zinc, cast,	,, . .	322	Antimony	,, . .	923
Lead	,, . .	351	Palladium,	,, . .	1000
Tin, pure,	,, . .	403	Platinum,	,, . .	1167
Tin, impure,	,, . .	516	Glass,	,, . .	1160
Silver,	,, . .	524	Marble,	,, . .	2833
Copper,	,, . .	581	Iron, soft	,, . .	818
Brass,	,, . .	584	Iron, cast	,, . .	900
Gold,	,, . .	682	Steel, tempered	,, . .	806
Bismuth,	,, . .	719	Steel	,, . .	926

Sheet zinc as employed on roofs of buildings or for covering locomotive boilers, exhibits in a marked manner the effects of expansion, in causing it to "blister and crack," which renders it an inferior article for such purposes.

The following tables will further illustrate this property of heat.

Table No. 7.

EXPANSION OF FLUIDS BY THE ADDITION OF 180° OF HEAT, OR AT 212° TAKING THE BULK OR VOLUME AT 32° AS 1 CUBIC FOOT.

Name.			Cub. ft.	Cub. ft.
Air . . .	1 part in	2·73 or	1000 become	1366
Alcohol . .	1	9	1000	1110
Nitric acid (s. g. 1·4) .	1	9	1000	1111
Fixed oils . .	1	12	1000	1083
Turpentine . .	1	14	1000	1071
Sulphuric ether . .	1	14	1000	1071
Sulphuric acid (s. g. 1·85)	1	17	1000	1058
Muriatic acid (s. g. 1·137)	1	17	1000	1058
Salt water . .	1	20	1000	1050
Water . . .	1	22	1000	1045
Mercury . .	1	55	1000	1018
Mercury, apparent in glass	1	64	1000	1015.

Table No. 8.

COMPARATIVE EXPANSION OF WATER AND AIR BY HEAT.

Deg. Fah.	Water.	Air.	Deg. Fah.	Water.	Air.
12	1·00236		122	1·01116	1·198
22	1·00092		132	1·01367	1·219
32	1·00022	1·000	142	1·01638	1·239
40	1·00000	1·021	152	1·01934	1·259
52	1·00021	1·047	162	1·02245	1·279
62	1·00083	1·071	172	1·02575	1·299
72	1·00180	1·093	182	1·02916	1·319
82	1·00312	1·114	192	1·03265	1·338
92	1·00477	1·136	202	1·03634	1·357
102	1·00672	1·156	212	1·04012	1·376
112	1·00880	1·177			

Thermometers.

The general law of expansion by heat, as shown in these tables, suggested the mode of measuring the heat in any body by comparison with the rate of expansion in a given body. The medical advantages of determining the comparative temperatures of the body and the air in sick chambers, led Sanctori, an Italian physician, to construct an air thermometer in 1590, to aid him in his practice, being the earliest we have an account of. In 1655 alcohol was substituted for air, and although both air and spirit thermometers are still employed in scientific investigations at very high or very low temperatures, mercurial thermometers are generally used.

The qualities of mercury for the thermometer are its fluidity through a range of nearly 700° under atmospheric pressure, and about 630° in the vacuum of a thermometer, where its fluidity extends below the freezing point of water, about 40°, and above its boiling point, 378°. It is not, however, a perfect instrument, as its rate of expansion increases for equal increments of heat at high temperatures, and it also deteriorates by use, which renders it necessary to check its indications for minute investigations by the more uniform expansion of the air thermometer.

Quicksilver was its original name, but the alchemists of

old fancied that the metals had some mysterious relation to the heavenly bodies. Thus they called :

Gold, the Sun ; Silver, Moon ; Quicksilver, Mercury ; Copper, Venus ; Iron, Mars ; Tin, Jupiter ; Lead, Saturn.

If they were unable to find the *elixir vitæ*, or the philosopher's stone, yet amid their visionary schemes, science is indebted to their researches, and quicksilver retains the name they gave it in ordinary use. As a metal, mercury has a beautiful silvery appearance, and both in art and in medicine it is extensively employed. The following are a few of its exponents; like other instances of the same kind experimentalists do not all give the same exponents.

Its specific gravity when solid at 40° below zero, is 13·64 times the weight of water of an equal bulk. At 60° it is 13·58; at 212° it is 13·37, and at 590° it begins to boil in the thermometer, but not until 660° in the open air.

Mercurial Thermometer.

This instrument is usually made with a slender glass tube of equal bore, having an enlarged end, which, with a part of the tube, is filled with mercury. It is then made to boil, that the expansion of the mercury may expel the air from the unfilled part of the tube, when the open end is fused together to prevent the admission of any more air. Thus enclosed from the pressure of the atmosphere, the mercury ascends by expansion as heat is communicated to it, or descends by contraction as heat is withdrawn from it. To give two fixed points in a scale of parts for the rise and fall of mercury, Dr. Hook suggested, and Sir I. Newton adopted the freezing and boiling points of water for that purpose, which is still acted upon.

These points are obtained by immersing the prepared tube containing mercury, alternately in freezing and boiling water, and marking the level at which the mercury becomes stationary in each trial. The distance between these points is then divided into a number of equal parts, and the scale extended as required. In this country thermometers are understood to be so adjusted, when the pressure of the air supports 30 inches of mercury.

Although philosophers have agreed on the fixed points of the thermometric scale, it is greatly to be regretted that they have not equally agreed on its division into equal parts, and not complicated research by a variety of scales. The distance between the freezing and boiling points is by Fahrenheit divided into 180 parts, by De Lisle into 150 parts, by Celsius into 100 parts, and by Reaumur into 80 parts, all in use in different parts of Europe. Diagrams, Nos. 4, 5, 6, 7, will show the relation these scales bear to each other.

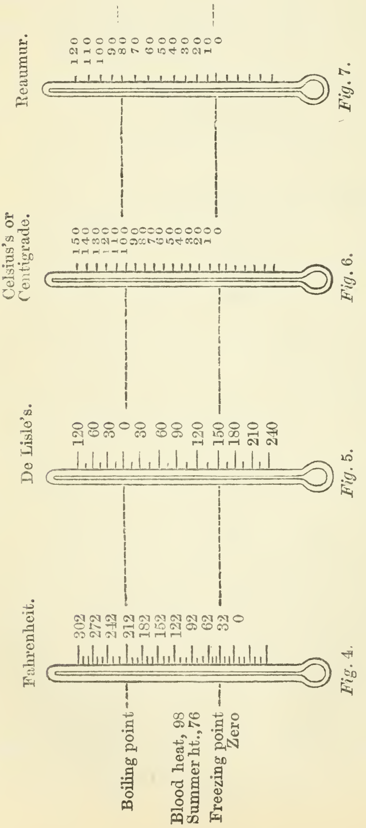


Fig. 4. $1=\frac{5}{9}$ of 1 of Cent.; or $=\frac{4}{9}$ of 1 of Reaum.; or $=\frac{5}{6}$ of 1 of De Lisle's.

Fig. 5. $1=1\frac{1}{3}$ of 1 of Fah.; or $=\frac{10}{15}$ of 1 of Cent.; or $=\frac{8}{15}$ of 1 of Reaum.

Fig. 6. $1=1\frac{1}{2}$ of 1 of De Lisle's; or $=\frac{4}{5}$ of 1 of Reaum.; or $=1\frac{4}{5}$ of 1 of Fah.

Fig. 7. $1=1\frac{1}{5}$ of 1 of Cent.; $1=2\frac{1}{4}$ of 1 of Fah.; $1=1\frac{7}{8}$ of 1 of De Lisle's.

Comparatively, therefore, the preceding thermometers stand thus :—

	Fahr.		De Lisle.		Celsius or Cent.		Reaum.
Boiling	212		0		100		80
Freezing	32		150		0		0
No. of equal parts	= 180		150		100		80
Ratio of parts	= 9	=	7·5	=	5	=	4

or thus :—

1° of Fahr.	$= \frac{5}{6}$ of 1 of De Lisle's	or Fahr.	$\times \frac{5}{6}$ = De Lisle's.
1 ,,	$= \frac{5}{9}$ of 1 of Cent.	,,	$\times \frac{5}{9}$ = Cent.
1 ,,	$= \frac{4}{9}$ of 1 of Reaum.	,,	$\times \frac{4}{9}$ = Reaum.
1° of De Lisle's	$= 1\frac{1}{3}$ of 1 of Fahr.	or De Lisle's	$\times \frac{4}{5}$ = Fahr.
1 ,,	$= \frac{10}{15}$ of 1 of Cent.	,,	$\times \frac{10}{15}$ = Cent.
1 ,,	$= \frac{8}{15}$ of 1 of Reaum.	,,	$\times \frac{8}{15}$ = Reaum.
1° of Cent.	$= 1\frac{4}{5}$ of 1 of Fahr.	or Cent.	$\times \frac{9}{5}$ = Fahr.
1 ,,	$= 1\frac{1}{2}$ of 1 of De Lisle's	,,	$\times \frac{3}{2}$ = De Lisle's.
1 ,,	$= \frac{4}{5}$ of 1 of Reaum.	,,	$\times \frac{4}{5}$ = Reaum.
1° of Reaum.	$= 2\frac{1}{4}$ of 1 of Fahr.	or Reaum.	$\times \frac{9}{4}$ = Fahr.
1 ,,	$= 1\frac{7}{8}$ of 1 of De Lisle's	,,	$\times \frac{15}{8}$ = De Lisle's.
1 ,,	$= 1\frac{1}{5}$ of 1 of Cent.	,,	$\times \frac{6}{5}$ = Cent.

The multipliers are thus used—

$$180 \text{ Fahr.} \times \tfrac{5}{6} = \frac{180 \times 5}{6} = 150^\circ \text{ De Lisle's.}$$

$$150 \text{ DeLisle's} \times \tfrac{6}{5} \text{ or } 1{\cdot}2 = \frac{150 \times 6}{5} = 180^\circ \text{ Fahr.}$$

$$\text{or } 150 \times 1{\cdot}2 = 180^\circ \text{ Fahr.}$$

$$80 \text{ Reaum.} \times \tfrac{15}{8} = \frac{80 \times 15}{8} = 150^\circ \text{ De Lisle's.}$$

$$180 \text{ Fahr.} \times \tfrac{5}{9} = \frac{180 \times 5}{9} = 100 \text{ Cent.}$$

$$100 \text{ Cent.} \times \tfrac{9}{5} \text{ or } 1{\cdot}8 = \frac{100 \times 9}{5} = 180 \text{ Fah.}$$

$$\text{or } 100 \times 1{\cdot}8 = 180^\circ \text{ Fahr.}$$

Whilst by these multipliers we are enabled to convert the degrees of one into those of the other, yet, as their notation is different, it requires attention to subtract the 32° of Fahrenheit from the reading off other scales, before the multiplier is used. Thus, Fahr. $212^\circ - 32 \times \frac{5}{9} = 100^\circ$ Cent.

From the freezing point to zero, it requires the number for a Fahrenheit scale to be subtracted from 32°. Thus,

Fahr. 14, then $32 - 14 \times \frac{5}{9} = 10$ Cent.

Below zero, it requires the 32° to be added. Thus,

Fahr. $-58^\circ + 32^\circ \times \frac{5}{9} = 50^\circ$ Cent.

and in like manner with Reaumur's scale.

De Lisle's notation commencing at 212° Fahrenheit's, 100° Cent. and 80° Reaumur, requires the quantity found by the multipliers to be deducted from 150° for the reading on his scale: thus 206 Fah. = 5 De Lisle's, for

$$\frac{206 - 32 \times 5}{6} = 145 \text{ and } 150 - 145 = 5^\circ \text{ De Lisle's.}$$

For it will be observed they differ in their zero or starting point as well as in their scale of parts. In 1709 Fahrenheit having artificially obtained a degree of cold 32° below the freezing point of water, imagined it to be the greatest possible cold, and fixed it as the starting point for his scale used in this country. Recent experiments have, however, gone as low as 448° below Fahrenheit's zero, and Dulong and Petit regard the point where heat is not to be found at all, as undefinable. As cold is only the expression for the comparative absence of heat, the greatest degree of cold it appears is not determinable. In 1730 Reaumur fixed his zero at the freezing point, so also did Celsius, whose scale is used in France, but in 1733, De Lisle fixed his zero at the boiling point. Thus, in reading off De Lisle's own scale, say at 80°, it would be 150° (the range between boiling and freezing) – 80 = 70° above the freezing point.

From this brief explanation of the principal thermometers

it will be obvious that one uniform scale, such as the centigrade or decimal scale, would be far preferable for both scientific and practical purposes, than a constant recourse to calculation to ascertain the comparative temperatures.

In this respect the following table will be found useful.

Table No. 9.

COMPARATIVE TEMPERATURES OF FAHR., DE LISLE, CELSIUS, REAUM., FROM 600° FAHR. TO FREEZING POINT OF MERCURY.

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
600	323·3	315·5	252·4	338	105·	170·	136·
580	306·6	304·4	243·5	337	104·1	169·4	135·5
560	290·6	293·3	234·6	336	103·3	168·8	134·1
540	273·3	282·2	225·7	335	102·5	168·3	134·6
520	256·6	271·1	216·8	334	101·6	167.7	134·2
500	240·	260·	208·	333	100·8	167·2	133·7
490	231·6	254·4	203·5	332	100·	166·6	133·3
480	223·3	248·8	199·1	331	99·1	166·1	132·8
470	215·	243·3	194·6	330	98·3	165·5	132·4
460	206·6	237·7	199·2	329	97·5	165·	132·
450	198·3	232·2	185·8	328	96·6	164·4	131·5
440	190·	226·6	181·4	327	95·8	163·8	131·1
430	181·6	221·1	176 8	326	95·	163·3	130·6
420	173·3	215·5	172·4	325	94·1	162·7	130·2
410	165·	210·	168·	324	93·3	162·2	129·7
400	156·6	204·4	163·5	323	92·5	161·6	129·3
395	152·4	201·6	161·3	322	91·6	161·1	128·8
390	148·3	198·8	159·1	321	90·8	160·5	128·4
385	144·1	196·1	156·9	320	90·	160·	128·
380	140·	193·2	154·6	319	89·1	159·4	127·5
375	135·8	190·5	152·4	318	88·3	158·8	127·1
370	131·6	187·7	150·2	317	87·5	158·3	126·6
365	127·5	185·	148·	316	86·6	157·7	126·2
360	123·3	182·2	145·8	315	85·8	157·2	125·7
355	119·16	179·4	143·5	314	85·	156·6	125·3
350	115·	176·6	141·3	313	84·1	156·1	126·8
345	110·83	174·	139·	312	83·3	155·5	124·4
340	106·6	171·1	136·8	311	82·5	155·	124·
339	105·8	170·5	136·4	310	81·6	154·4	123·5

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
309	80·8	153·8	123·1	265	44·1	129·4	103·5
308	80·	153·3	122·6	264	43·3	128·8	103·1
307	79·1	152·7	122·2	263	42·5	128·3	102·6
306	78·3	152·2	121·7	262	41·6	127·7	102·2
305	77·5	151·6	121·3	261	40·8	127·1	101·7
304	76·6	151·1	120·8	260	40·	126·6	101·3
303	75·8	150·5	120·4	259	39·1	126.1	100·8
302	75·	150·	120·	258	38·3	125·5	100·4
301	74·1	149·4	119·5	257	37·5	125·	100·
300	73·3	148·8	119·1	256	36·6	124·4	99·5
299	72·5	148·3	118·6	255	35·8	123·8	99·1
298	71·6	147·7	118·2	254	35·	123·3	98·6
297	70·8	147·2	117·7	253	34·1	122·7	98·2
296	70·	146·6	117·3	252	33·3	122·2	97·7
295	69·1	146·1	116·8	251	32·5	121·6	97·3
294	68·3	145·5	116·4	250	31·6	121·1	96·8
293	67.5	145·	116·	249	30·8	120·5	96·4
292	66·6	144·4	115·5	248	30·	120·	96·
291	65·8	143·8	115·1	247	29·1	119·4	95·5
290	65·	143·3	114·6	246	28·3	118·8	95·1
289	64·1	142·7	114·2	245	27·5	118·3	94·6
288	63·3	142·2	113·7	244	26·6	117·7	94·2
287	62·5	141·6	113·3	243	25·8	117·2	93·7
286	61·6	141·1	112·8	242	25·	116·6	93·3
285	60·8	140·5	112·4	241	24·1	116·1	92·8
284	60·	140·	112·	240	23·3	115·5	92·4
283	59·1	140·4	111·5	239	22·5	115·	92·
282	58·3	139·8	111·1	238	21·6	114·4	91·5
281	57·5	139·3	110·6	237	20·8	113·8	91·1
280	56·6	138·7	110·2	236	20·0	113·3	90·6
279	55·8	138·2	109·7	235	19·1	112·7	90·2
278	55·	137·6	109·3	234	18·3	112·2	89·7
277	54·1	136·1	108·8	233	17·4	111·6	89·3
276	53·3	135·5	108·4	232	16·6	111·1	88·8
275	52·5	135·	108·	231	15·8	110·5	88·4
274	51·6	134·4	107·5	230	15·	110·	88·
273	50·8	133·8	107·1	229	14·1	109·4	87·5
272	50·	133·3	106·6	228	13·3	108·8	87·1
271	49·1	132·7	106·2	227	12·5	108·3	86·6
270	48·3	132·2	105·7	226	11·6	107·7	86·2
269	47·5	131·6	105·3	225	10·8	107·2	85·7
268	46·6	131·1	104·8	224	10·	106·6	85·3
267	45·8	130·5	104·4	223	9·1	106·1	84·8
266	45·	130·	104·	222	8·3	105·5	84·4

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
221	7·5	105·	84·	177	29·1	80·5	64·4
220	6·6	104·4	83.5	176	30·	80·	64·
219	5·8	103·8	83·1	175	30·8	79·4	63·5
218	5·0	103·3	82·6	174	31·6	78·8	63·1
217	4·1	102·7	82·2	173	32·5	78·3	62.6
216	3·3	102·2	81·7	172	33·3	77·7	62·2
215	2·5	101·6	81·3	171	34·1	77·2	61·7
214	1·6	101·1	80·8	170	35·	76·6	61·3
213	·8	100·5	80·4	169	35·8	76·1	60·8
212	zero	100·	80·	168	36·6	75·5	60·4
211	·8	99·4	79·5	167	37·5	75·	60·
210	1·6	98·8	79·1	166	38·3	74·4	59·5
209	2·5	98·3	78·6	165	39·1	73·8	59·1
208	3·3	97·7	78·2	164	40·	73·3	58·6
207	4·1	97·2	77·7	163	40·8	72·7	58·2
206	5·0	96·6	77·3	162	41·6	72·2	57·7
205	5·8	96·1	76·8	161	42·5	71·6	57·3
204	6·6	96·5	76·4	160	43·3	71·1	56·8
203	7·5	95·0	76·	159	44·1	70·5	56·4
202	8·3	94·4	75·5	158	45·	70·	56·
201	9·1	93·8	75·1	157	45·8	69·4	55·5
200	10·	93·3	74·6	156	46·6	68·8	55·1
199	10·8	92·7	74·2	155	47·5	68·3	54·6
198	11·6	92·2	73·7	154	48·3	67·7	54·2
197	12·5	91·6	73·3	153	49·1	67·2	53·7
196	13·3	91·0	72·8	152	50·	66·6	53·3
195	14·1	90·5	72·4	151	50·8	66·1	52·8
194	15·	90·	72·	150	51·6	65·5	52·4
193	15·8	89·4	71·5	149	52·5	65·	52·
192	16·6	88·8	71·1	148	53·3	64·4	51·5
191	17·5	88·3	70·6	147	54·1	63·8	51·1
190	18·3	87·7	70·2	146	55·	63·3	50·6
189	19·1	87·2	69·7	145	55·8	62·7	50·2
188	20·	86·6	69·3	144	56·6	62·2	49·7
187	20·8	86·1	68·8	143	57·5	61·6	49·3
186	21·6	85·5	68·4	142	58·3	61·1	48·8
185	22·5	85·	68·	141	59·1	60·5	48·4
184	23·3	84·4	67·5	140	60·	60·	48·
183	24·1	83·8	67·1	139	60·8	59·4	47·5
182	25·	83·3	66·6	138	61·6	58·8	47·1
181	25·8	82·7	66·2	137	62·5	58·3	46·6
180	26·6	82·2	65·7	136	63·3	57·7	46·2
179	27·5	81·6	65·3	135	64·1	57·2	45·7
178	28·3	81·1	64·8	134	65·	56·6	45·3

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
133	65·8	56·1	44·9	89	102·5	31·6	25·3
132	66·6	55·5	44·4	88	133·3	31·1	24·8
131	67·5	55·	44·	87	104·1	30·5	24·4
130	68·3	54·4	43·5	86	105·	30·	24·
129	69·1	53·8	43·1	85	105·8	29·4	23·5
128	70·	53·3	42 6	84	106·6	28·8	23·1
127	70·8	52·7	42·2	83	107·5	28·3	22·6
126	71·6	52·2	41·7	82	108·3	27·7	22·2
125	72·5	51·6	41·3	81	109·1	27·2	21·7
124	73·8	51·1	40·8	80	110·	26·6	21·3
123	74·1	50.5	40·4	79	110·8	26·1	20·8
122	75·	50·	40·	78	111·6	25·5	20·4
121	75·8	49·4	39·5	77	112·5	25·	20·
120	76·6	48·8	39·1	76	113·3	24·4	19·5
119	77·5	48·3	38·6	75	114·1	23·8	19·1
118	78·3	47·7	38·2	74	115·	23·3	18·6
117	79·1	47·2	37·7	73	115·8	22·7	18·2
116	80·	46·6	37·3	72	116·6	22·2	17·7
115	80·8	46·1	36·8	71	117·5	21·6	17·3
114	81·6	45·5	36·4	70	118·3	21·1	16·8
113	82·5	45·	36·	69	119·1	20·5	16·4
112	83·3	44·4	35·5	68	120·	20·	16·
111	84·1	43·8	35·1	67	120·8	19·4	15·5
110	85·	43·3	34·6	66	121·6	18·8	15·1
109	85·8	72·7	34·2	65	122·5	18·3	14·6
108	86·6	42·2	33·7	64	123·3	17·7	14·2
107	87·3	41·6	33·3	63	124·1	17·2	13·7
106	88·3	41·1	32·8	62	125·0	16·6	13·3
105	89·1	40·5	32·4	61	125·8	16·1	12·8
104	90·	40·	32·	60	126·6	15·5	12·4
103	90·8	39·4	31·5	59	127·5	15·	12·
102	91·6	38·8	31·1	58	128·3	14·4	11·5
101	92·5	38·3	30·6	57	129·1	13·8	11·1
100	93·3	37·7	30·2	56	130·	13·3	10·6
99	94·1	37·2	29·7	55	130·8	12·7	10·2
98	95·	36·6	29·3	54	131·6	12·2	9·7
97	95·8	36·1	28·8	53	132·5	11·6	9·3
96	96·6	35·5	28·4	52	133·3	11·1	8·8
95	97·5	35·	28·	51	134·1	10·5	8·4
94	98·3	34·	27·5	50	135·	10·	8·
93	99·1	33·4	27·1	49	135·8	9·4	7·5
92	100·	33·8	26·6	48	136·6	8·8	7·1
91	100·8	32·7	26·2	47	137·5	8·3	6·6
90	101·6	32·2	25·7	46	138·3	7·7	6·2

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
45	139·1	7·2	5·7	1	175·8	17·2	13·7
44	140·	6·6	5·3	zero	176·6	17·7	14·2
43	143·8	6·1	4·8	1	175·8	18·3	14·6
42	141·6	5·5	4·4	2	178·3	18·8	15·1
41	142·5	5·	4·	3	179·1	19·4	15·5
40	143·3	4·4	3·5	4	180·	20·	16·
39	144·1	3·8	3·1	5	180·8	20·5	16·4
38	145·	3·3	2·6	6	181·6	21·1	16·8
37	145·8	2·7	2·2	7	182·5	21·6	17·3
36	146·6	2·2	1·7	8	183·3	22·2	17·7
35	147·5	1·6	1·3	9	184·1	22·7	18·2
34	148·3	1·1	0·8	10	185·	23·3	18·6
33	149·1	0·5	0·4	11	185·8	23·8	19·1
32	150·	zero	zero	12	186·6	24·4	19·5
31	150·8	0 5	0·4	13	187·5	25·	20·
30	151·6	1·1	0·8	14	188·3	25·5	20·4
29	152·5	1·6	1·3	15	189·1	26·1	20·8
28	153·3	2·2	1·7	16	190·	26·6	21·3
27	154·1	2·7	2·2	17	190·8	27·2	21·7
26	155·	3·3	2·6	18	191·6	27·7	22·2
25	155·8	3·8	3·1	19	192·5	28·3	22·6
24	156·6	4·4	3·4	20	193·3	28·8	23·1
23	157·5	5·	4·	21	194·1	29·4	23·5
22	158·3	5·5	4·4	22	195·	30·	24·
21	159·1	6·1	4·8	23	195·8	30·5	24·4
20	160·	6·6	5·3	24	196·6	31·1	24 8
19	160·8	7·2	5·7	25	197·5	31·6	25·3
18	161·6	7·7	6·2	26	198·3	32·2	25·7
17	162·5	8·3	6·6	27	199·1	32·7	26·2
16	163·3	8·8	7·1	28	200·	33·3	26·6
15	164·1	9·4	7·5	29	200·8	33 8	27·1
14	165·	10·	8·	30	201·6	34·4	27·5
13	165·8	10·5	8·4	31	202·5	35·	28·
12	166·6	11·1	8·8	32	203·3	35·5	28·4
11	167·5	11·6	9·3	33	204·1	36·1	28·8
10	168·3	12·2	9·7	34	205·	36·6	29·5
9	169·1	12·7	10·2	35	205·8	37·2	29·7
8	170·	13 3	10·6	36	206·6	37·7	30·2
7	170·8	13·8	11·1	37	207·5	38·3	30·6
6	171·6	14·4	11·5	38	208·3	38·8	31·1
5	172·5	15·	12·	39	209·1	39·4	31·5
4	173·3	15 5	12·4	40	210·	40·	32·
3	174·1	16·1	12·8	41	210·9	40·5	32·4
2	175·	16·6	13·3	42	211·6	41·1	32·9

The following table exhibits a few of the effects of heat, which may be instructive.

Table No. 10.

EFFECTS OF HEAT.

		Fahr. below zero.
Artificial cold produced by Thelorier		133
Solid alcohol and carbonic acid	melts	121
Artificial cold produced by Walker		91
Natural cold observed by Ross		60
,, ,, of planetary space (Fourc.)		58
,, ,, observed by Parry		55
,, ,, ,, at Hudson's Bay		50
,, ,, ,, at Glasgow, 1780		23
Liquid ammonia	melts	46
Nitric acid (sp. gr. 1·424)	melts	46 boils 210°
Mercury	freezes	39 boils 660°

,, expands 1 in $55\frac{1}{2}$ from 32 to 212, or 1·80 per cent.
,, ,, 1 in $54\frac{1}{4}$ from 212 to 392, or 1·83 ,,
,, ,, 1 in 53 from 392 to 472, or 1·88 ,,
,, ,, 1 in 64·8 in glass tubes,* or 1·54 ,,

Dulong and Petit.

Creosote	still fluid at	17 boils 397°
Oil of vitriol	freezes	13
Bromine	melts	10 boils 117°
Water 1, alcohol 1	temp.	7
,, 1, snow 1	temp.	zero of Fah.
,, 1, salt 3	temp.	4 above zero
,, 78, salt 22	temp.	7
Turpentine	freezes	14 boils 314°
Strong wine	freezes	20

Blood, human, freezes 25; life heat, 98; fever heat, 107.

,, ,, composed of water, 78·56; colouring matter, (Hematosin and Globulin,) 11·962.

Albumen, 6·94; fatty matter, ·43; fibrin, ·356; oily matter, ·227; albumen combined with soda, ·202; extractive matter, ·192; portions of chlo-

* From the expansion of the glass tube.

ride of sodium, potassium, carbonates, phosphates and sulphates of potash and soda altogether, ·73 ; carbonates of lime and magnesia, phosphates of lime, magnesia and iron, and peroxide of iron, altogether, ·142 ; loss in analyses, ·258 ; total, 100.—*M. Lecance.*

Sea water (salt 1, water 29), . . . freezes 28 boils 224°
Milk freezes 30, ferments 100, yielding some alcohol.
Ordinary milk contains—

	Water,	Sugar,	Butter,	Cheese,	Salts or mucous matter,	Total,
Woman's .	87·98	6·50	3·55	1·52	·45	100
Ass's . .	91·65	6·08	0·11	1·82	·34	100
Cow's . .	87·02	4·77	3·13	4·48	·60	100

Henry Chevallier.

Water freezes 32, boils 212°, fixed thermometrical points

			measures	per cent.
Water in cooling from	212° to 189·5	contracts	18 in 2000,	or ·9
,, ,, ,, ,,	189·5 to 167	,,	16·2 in ,,	or ·81
,, ,, ,, ,,	167· to 144·5	,,	13·8 in ,,	or ·69
,, ,, ,, ,,	144·5 to 122	,,	11·5 in ,,	or ·575
,, ,, ,, ,,	122· to 99·5	,,	9·3 in ,,	or ·465
,, ,, ,, ,,	99·5 to 77	,,	7·1 in ,,	or ·355
,, ,, ,, ,,	77· to 54·5	,,	3·9 in ,,	or ·195
,, ,, ,, ,,	54·5 to 32	,,	0·2 in ,,	or ·001

Rumford.

Olive oil, freezes 36
Phosphorus burns slowly at 43, vividly at 122, boils at 554
Mean temp. of the earth's surface 50
,, of our climate . 52
Vinous fermentation begins . 59, rapid at 77
Acetous ,, . . 77, ceases at 88
Animal putrefaction from . . 66 to 135
Summer heat in this country . 75 to 80
Heat in Great Exhibition, June 26, 1851, Floor, 85, Galleries, 95.
Carbonic acid . . melts, 85
Tallow 92
Animal heat . . . 96 to 100
Spermaceti . . . melts, 112
Sulphuret of carbon . ,, 116
Wax, yellow . . ,, 142, white 155
Stearic acid (per Chandler) ,, 158—167

Alcohol . . .	boils, 173
Sodium . . .	melts, 190
Bismuth 2, lead 1, tin 1 .	„ 201 (Rose's metal)
Steam from ordinary water, begins to form,	212
,, sea water ,,	224
Sulphur . . .	melts, 218, boils, 570
Iodine . . .	„ 225, boils 347, burns 363
Tin 1, Bismuth 1 . .	„ 289
Essential oils . .	boil, 320
Steel (tempering) pale yellow	temp. 330, deep blue, 580
Tin 2, Lead 1 (soft solder)	melts, 360
Tin and Cadmum . .	„ 442
Tin 1, Lead 3 (coarse solder)	„ 480
Bismuth . . .	„ 476 to 507
Lead . . .	„ 594 to 612
Whale oil . .	boils, 630
Iron, red heat in the dark . .	635, in the light 980
Linseed oil . . .	640
Nickel magnets lose their polarity .	630
Zinc . . .	melts, 680 to 773
Hydrogen . .	burns, 800
Charcoal . . .	„ 802
Antimony . .	melts, 797, 812
Common . .	temp. 1141
Bronze (100 copper, 10 tin)	melts, 1652
Brass . . .	„ 1869
Copper . . .	„ 1996
Silver (variously stated) .	„ 1832, 1873, 2233
Gold . . .	„ 2016, 2182
,, Money (Gold 11, Copper 1)	„ 2150
Steel . . .	„ 2372 to 2552
Cast Iron, variously stated as	2732, 2786, 3479
Air Furnace . .	3500

Sources of Heat.

The chief sources of heat are the Sun, the Earth, Electricity, Friction, Percussion, Compression, and Chemical Action. There is a difference between the rays of heat from the sun

which passes through glass like light, whilst the rays of heat from a fire are arrested and absorbed by the glass, and only very slowly pass through it. The effect of the rays of the sun in extinguishing a common fire are also well known.

Electric heat, like common heat, is also arrested by glass, which is accordingly employed as an insulate in electric experiments.

What heat really is so much perplexes the closest investigators, that it may be submitted, as a question to be solved by electricians, whether there is a point under the ordinary or extraordinary combinations of heat and water as applied to generate steam, when electricity would be engendered and communicated to the water. If there is such a point, and electric and common heat are only different degrees of concentration of the same body, then the great difficulty regarding steam-boiler explosions would be more satisfactorily solved than has yet been done.

Heat is communicated to other bodies in three ways,

1st. By direct contact, called *Conduction.*

2nd. By right lines, called *Radiation.*

3rd. By carrying, called *Convection.*

Conduction.

When two bodies of unequal temperature are placed in contact with each other, the hotter body communicates heat to the colder body until they become of equal temperature. The rapidity of this equalization depends upon the nature of the bodies themselves, as all bodies do not conduct heat alike, and are accordingly called good or bad conductors. Wood, for instance, is so bad a conductor of heat, that if a piece of it be set on fire at one end it can be held until the flame has reached the hand without the heat having been previously conducted by the fibres of the wood itself. Glass is also a bad conductor of heat. Fluids also conduct heat very slowly, mercury excepted.

Metals are good conductors, but vary in their power of doing so, as seen in the following tabular classification of their comparative powers of conduction.

Gold	1000	Tin	303·9
Platina	381	Lead	179·6
Silver	973	Marble	23·6
Copper	898·2	Porcelain	12·2
Iron	374·3	Fire Clay	11·4
Zinc	363	Water	9·

The conducting power of metals may be experienced by holding the point of a pin in the flame of a candle, when the heat is rapidly conducted to the head until it cannot be held by the uncovered fingers.

Atmospheric air and gases have been generally regarded as bad conductors of heat; but recent investigators consider that the atmosphere conducts heat as rapidly as it does sound, but that their effects are rendered almost invisible from the small quantity of ponderable matter in the air.

The conduction of heat through a body is by some regarded as radiated, by others as communicated from particle to particle within the body, and the rapidity of communication regulated by the density and molecular construction of the body.

Radiation.

When a hot body, such as a fire or a mass of metal, is surrounded by other bodies not in immediate contact, but placed at some distance from it, the heat from the hot body radiates from the centre in lines to the colder bodies, with a power inversely as the square of the distance from the centre. The greatest effect is upwards, the least effect is horizontally to the surface. The surface of the bodies receiving heat exercises a marked effect on the quantity absorbed in a given time. It was shown by Leslie that a tin vessel filled with hot water

and covered over with lamp black possessed a radiating power = 100, but

Covered with	sealing wax	95
,, ,,	writing paper	98
,, ,,	resin	96
,, ,,	crown glass	91
,, ,,	china ink	88
,, ,,	red lead	80
,, ,,	plumbago or black lead	75
,, ,,	isinglass	75
,, ,,	tarnished lead	45
,, ,,	scratched tin	22
,, ,,	bright lead	19
,, ,,	mercury	20
,, ,,	polished iron	15
,, ,,	sheet tin	12

Here lamp black and white paper have nearly the same power, whilst China ink and black lead have much less. A thermometer is more affected by an equal amount of heat when coated with chalk than when coated with Indian ink, and a thermometer made with coloured spirits rises more, for equal heat, than an uncoloured one.

For instance, painted bodies having a metallic surface from the paint radiate much more than the same bodies not painted. Hammered metallic bodies radiate slower than when less dense, as hammered silver has only a radiating power of 10, but not hammered of 13·7. When the surface of each is scratched the radiating power is inversely affected, for the hammered is 18 and the cast only 11·3. This leads to the inference that radiation depends upon a thin film at the surface regulated by the density, for the increase of rough burnished silver is $\frac{4}{5}$ of that of polished hammered, while the cast rough decreases $\frac{1}{5}$ from that of polished cast silver. The absorbing power of a body is usually reckoned as equal to its radiating power.

Colour was long held to affect radiation, but that is now found untenable. It owed its probability to the observed effects of the heat of the sun in radiating most from black, less from blue, green, red, yellow, and white, in the order in which they stand, when acted upon by heat combined with light. Absorption of ordinary heat without light depends, as has been seen, more upon the nature of the surface than of the colour.

It was also generally supposed that there was some ratio between radiated and conducted heat; but it is now ascertained that it only approximates at low but not at high temperatures, and that at 60 to 120 Cent. it is as 3 to 7, at 60 to 130 Cent. as 3 to 13, and at 60 to 240 Cent. as 3 to 21, whilst on the old law these numbers would have been 6, 9, 12, instead of 7, 13, 21.

The properties of passing heat and light through bodies appear to have little relation, and Mellorie regards them as being inversely to each other. Thus blackened glass passes heat but scarcely any light, and wood passes neither. Of transparent bodies mineral salt passes 92 per cent. of heat, but alum only 12 per cent.

Radiation has therefore been considered as equal in power but inversely to absorption, and that at the same temperature the radiating and absorbing power of bodies are equal. Radiation may be defined to depend upon the facility of decomposing the particles, but absorption upon the inability to reflect them back. Much of the comparative economy of steam boilers depends upon their absorbing power; for no matter how ably the furnace performs its duty, if the heat given off from the fuel cannot be taken up as rapidly as it is produced, then of course economy ceases. The rapidity of production of heat in a locomotive furnace is not favourable for the entire absorption of that heat: hence the advantage of the numerous thin metal tubes to divide and absorb the heat generated in the furnace. It is not the least merit in this class of boilers, that as the velocity increases so does the area of conduction or

direct contact of the heat, whilst the area of radiation decreases in the same ratio. For as the draught upon the fire increases so does the length of the flame; consequently not only the fire box, but also a greater or lesser portion of the thin tubes in immediate contact with that flame, absorb heat by conduction, and the remainder of the tubular surface absorbs it by radiation from the passing gases.

Convection.

Convection or carrying is the power possessed by fluids of conveying heat acquired at one place to another place.

In boilers the heat is thus transmitted amongst the water. In the furnace the air carries the unabsorbed heat to the chimney. When the power of convection is much greater than the power of absorption, then the heat evolved during combustion is carried off without producing its proper effect. The greater therefore the absorbing power of any boiler, the greater will be its economy. In locomotive boilers at high velocities, this power of convection increases as the radiating surface decreases, and the loss of heat by convection is in proportion to the velocity of the escaping gases and the shorter distance passed over by them.

In solid bodies heat travels from atom to atom, but in fluid bodies, the heated parts fly off and colder ones take their place until the heat has been diffused. It is only by convection that air carries heat, for if its circulation be stopped it nearly ceases to carry heat. Glass also carries heat slowly, and it is estimated that a square foot of glass exposed on one side to the atmosphere will cool 1·279 cubic feet of air 1° per minute, when it is in contact with the glass, as seen in the condensation of the vapour in the air on it precisely as dew is formed on the grass.

A cast-iron pipe 3 inches diameter, and metal $\frac{1}{4}$ thick cooled down 1° in 1·21 min. with a black surface, in 1·25 min.

with an iron surface, and in 1·28 min. with a white painted one.

Reflecting Power.

The reflecting power of different bodies is generally estimated as being inversely as the radiating power, so that if brass reflects 100 parts of heat, silver would reflect 90, and with these others as they stand below.

Brass	100
Silver	90
Tinfoil	85
Block tin	80
Steel	70
Lead	60
Tin foil, softened by mercury	10
Glass	10
Glass, coated with wax	5

Specific Heat.

The specific heat, or the comparative capacity of bodies of equal weight to receive heat, varies widely. Thus, if 1lb. of mercury at 32° be mixed with water at 62°, the temperature will become 61°, or if the mercury had been 62° and the water 32°, the common temperature would have been 33°, showing that the capacity of mercury for heat is about $\frac{1}{30}$ of that of water. It may therefore be considered as the ratio of the heat in a given weight or volume to those of the standard body. Iron shows a specific heat of ·113 or $\frac{1}{9}$ that of water, and steam ·847. Water is usually made the standard of comparison for ponderous bodies, and air for gaseous bodies. The capacity of bodies for heat is also tested by the quantity of ice they will melt: thus, equal weights of iron and lead, heated to 100° would melt 11 grains by the iron, and only 3 grains by the lead, each falling to 95°. The same test applied to fuel has given the following results.

1 lb. of good coal	melts	90 lbs.	of ice.
,, coke	,,	84 lbs.	,,
,, wood	,,	32 lbs.	,,
,, wood charcoal	,,	95 lbs.	,,
,, peat	,,	18 lbs.	,,

It may be mentioned here that it was on this plan that Dr. Arnott tested the quantity of heat passing from a common fire up the chimney, and by the quantities of ice melted he found it more than the whole heat radiated out into the room, which melted less ice than the heat carried up the chimney.

The following is a table of a few specific heats.

Table No. 11.

SPECIFIC HEAT IN DIFFERENT BODIES.

	Regnault.	Dulong.		
Iron . .	·1137	·110	Hydrogen . .	3·2936
Copper .	·0951	·0949	Water . .	1·
Zinc . .	·0955	·0927	Steam . .	·847
Nickel .	·1086	·1035	Alcohol . .	·600 to ·700
Cobalt . .	·1069	·1498	Ether . .	·6600
Platinum .	·0324	·0314	Oil . .	·520
Gold . .	·0324	·0298	Air . . .	·2669
Sulphur . .	·2026	·1880	Nitrogen .	·2754
Carbon .	·2411	·25	Oxygen . .	·2361
Phosphorus .	·1887	·385	Carbonic acid .	·2210
Iodine . .	·05412	·089	,, oxide	·2884
Arsenic .	·0814	·081	Charcoal . .	·2631
Lead . .	·0314	·0293	Oil of turpentine . .	·426
Bismuth .	·0308	·0288		
Antimony .	·0507	·0507	Sulphuric acid.	·333
Indian Tin .	·05623	·0514	Nitric acid .	·426
Mercury .	·0333	·0330	Iron at 212° .	·110
Steel . .	·118		,, 392° .	·115
Brass . .	·094		,, 372° .	·122
Glass . .	·177		,, 662° .	·126
Salt . .	·225		,, carbonate of	·1819
Marble . .	·205		Zinc ,, .	·1712

The difference in the quantity of specific heat by different experimenters arises from the delicate nature of the experi-

ments and the manner of performing them, in which the minutest error becomes magnified when generalized.

The capacity for heat increases with the temperature, as seen in iron, and in cooling a greater amount of heat is given out in cooling down an equal number of degrees at a high than at a low temperature.

To raise 1 lb. of water from 32° to 212° or 180° requires as much heat as would raise 3·72 lbs of air through the same range. Strictly it is as ·2669 is to 1.

Relative Heat.

Specific heat is by equal weights of the compared bodies, but relative heat is by equal volumes. Thus the specific heat of steam is only ·847, but its relative heat is only $\frac{1}{228}$ that of an equal volume of water, and would lose as much heat in one minute as the water would do in 228 minutes. Relative heat is therefore directly as its specific heat and volume.

With gaseous bodies the specific heat is inversely as their specific gravity; hence equal quantities of such gases contain an equal quantity of heat less their specific gravity. As the relative weights of equal volumes of gas are inversely as their specific gravity, equal volumes will have equal relative heats. When mechanically mixed, such as the oxygen and nitrogen of the air, or the heat and water in steam, though of different densities, yet they have equal relative heat. When gases are chemically combined, they have a different relative heat above that of air, and each gas has its own relative heat, of which air is the unit of comparison. The relative heat of air to water is 0·2669, which multiplied into any aerial comparative exponent would give the comparison with water similarly to ponderous bodies.

Combustion, or the Production of Heat.

Heat appears to be a compound derived from the union of a combustible with an incombustible, which supports or sup-

plies the constituent part necessary to complete combustion, and without which definite supply combustion is imperfect. This combination infers different qualities of the two ingredients in the compound of heat. Strictly, the process of combustion is complex, and only partially understood. As far as regards its ordinary operation in the steam-boiler fireplace, we will endeavour to convey a clear exposition of its more important features.

A coal for instance thrown on a fire evolves amongst others, the two principal combustibles of carbon and hydrogen, which uniting with the oxygen of the air—an incombustible yet a necessary supporter of a fire—produces heat and light at the same time. Simple as this may appear, its analysis is yet a complicated chemical problem. The chief agents operating in the furnace are carbon, hydrogen and oxygen, and their union in certain proportions produces other bodies, as water or steam, carbonic oxide, carbonic acid, besides others of less practical importance.

Combustibles and Incombustibles.

A combustible body is one which actually burns, such as carbon. An incombustible body is one that does not itself burn. A supporter of combustion is one that does not burn, but gives strength and support to one that does burn, such as oxygen, which supports carbon in producing heat. A common fire exhibits the union of the carbon of the fuel and the oxygen of the air. A gas light exhibits the union of carbon, hydrogen, and oxygen to produce both heat and light. In neither process is the oxygen burnt, but only the combustibles, carbon and hydrogen. In all ordinary circumstances oxygen is therefore an indispensable element of combustion, and its proper supply a question of the first importance to economy of fuel. For instance, if only 8 parts of oxygen are admitted for each 6 parts of carbon evolved from the fuel, the combustion is very imperfect, and much of the heat of the fuel

passes off in combustible gases, of which carbonic oxide is the chief. If, however, 16 parts of oxygen are admitted to combine with 6 parts of carbon, the combustion is 70 per cent. better than the last, producing steam and carbonic acid as the products of perfect combustion. Under the ordinary pressure of the atmosphere, oxygen is the supporter, and carbon and hydrogen the combustibles, but in a vacuum, or under the intense action of the oxy-hydrogen blastpipe, invented by my friend Goldsworthy Gurney, Esq., and now attracting so much notice in the Crystal Palace—this natural order is reversed, and oxygen becomes the combustible and carbon the supporter of combustion.

The following are the usually received definitions of chemical combination, mechanical mixture and the elements of combustion.

Chemical Combinations.

When two bodies unite to form a third body distinct from either of the combining bodies, this is called chemical union, as when carbon and oxygen unite to form heat, carbonic oxide or carbonic acid, or with hydrogen to form water.

Mechanical Mixtures.

A mechanical mixture is one where the bodies have been brought together, but each retains its original qualities, such as sand and water, or the oxygen and nitrogen of the air, or heat and water in steam, all of which can be readily separated and restored to their original state again.

Atmosphere.

This important body which surrounds us, and supplies the oxygen, or *life* of our breath, besides its other invaluable features, is a mechanical mixture of one-fifth part of oxygen and four-fifth parts of nitrogen, sometimes called azote. The latter dilutes the former, and renders it adapted to the consti-

tution of man and the animal creation; and but for this dilution of the oxygen by the nitrogen, constituted as we are, life would be an accelerated but short course, similar to the brilliance exhibited by a wax taper when plunged into a jar of oxygen on the lecture table. Oxygen is therefore the principal supporter of both life and combustion; but the peculiar uses of nitrogen are only clearly understood as indispensable to vegetation. An ordinary iron furnace is estimated to require 310 tons of air in 24 hours, or as much as 20,000 men. That it is the oxygen which changes or supports ordinary combustion may be shown by covering an ordinary candle with a bell glass whose lower edge rests in water, to prevent a further supply of air inside the glass. As the enclosed oxygen is changed the flame grows less and less until it is extinguished, and the contents are found to be nitrogen apparently unaltered, hydrogen and carbonic acid. 100 cubic inches of air weigh 31 grains.

Oxygen.

This gas was discovered by Dr. Priestley in 1774, and is considered to be one of the most abundant bodies in nature. It is a permanent colourless transparent gas without smell, and 1·11 times heavier than air, and 100 cubic inches weigh 34·184 grains. It combines with many other bodies in a variety of ways, forming very distinctive compounds. For ordinary combustion and breathing it is supplied from the atmosphere, but for the lecture-room it can be readily obtained in several ways, one of which is by heating the chlorate of potash, and collecting the gas given off in a bladder or jar. If a taper with a single spark of fire left on its wick be placed in any jar of oxygen, it immediately burns forth with splendour, and iron when introduced is melted down in a shower of dazzling scintillations, forming oxide of iron.

Ordinary rust is also oxide of iron formed from the slow combustion of atmospheric temperature, whilst the intense

temperature of carbon and pure oxygen produce rapid combustion, and the smith's forge is only another degree of the same process. Phosphorus introduced amongst oxygen produces a volume of painfully brilliant light forming phosphoric acid.

The oxy-hydrogen light, as invented by Mr. Gurney, improved by Mr. Beechy, and exhibited by Mr. Abraham of Liverpool in the Great Exhibition, consists in bringing equivalent quantities of oxygen and hydrogen gases into a burner and igniting them, when they evolve vivid combustion and intense heat, melting all common metals with great ease. Lime, however, resists its fusive power, but evolves the most brilliant light then known, which is employed in the Polytechnic Institution for their microscopic views. Recently, however, a still more luminous light is produced by the action of electricity on two pieces of charcoal, and M. Lessel and Co. exhibit one of great illuminating power at the Crystal Palace, whose light when tried by the prism shows the solar spectrum rays of the light of the sun, viz., red, orange, yellow, green, blue, indigo, and violet.

Nitrogen.

This body neither supports life nor combustion. It is lighter than air, has no taste or smell, is little absorbed by water, and has no effect upon lime water. Its specific gravity is ·972 that of air, or 100 cubic inches weigh 30·15 grains. Although nitrogen has some properties in common with carbonic acid, one of the products of perfect combustion, it has also dissimilar ones, besides being an elementary body, while carbonic acid is a compound of oxygen and carbon. Nitrogen is necessary to life. Carbonic acid is poisonous. Protoxide of nitrogen forms the well-known laughing gas, which produces such an exhilarating flow of spirits and muscular energy, by a few inhalations of it, and its specific gravity is 1·527 that of air, or 100 cubic inches = 47·37 grains.

Carbon.

This is a finely-divided pulverulent mineral body in its ordinary state, forming the basis of most fuels, and found in many different forms; as it is obtained by various processes—from oil lamps, as lamp black; from coal, as coke; and from wood, as charcoal. It is the mineral particles of carbon in a state of combustion which render flame luminous from either gas, oil, or candles. Tallow or wax candles are a compound of carbon, oxygen and hydrogen. The diamond is pure carbon in a crystalline state, possessing the singular property of reflecting all the light which falls upon it at an angle of about 24°, whilst artificial gems only reflect half that light. The diamond is highly valued, and in much esteem as an article of dress, or to adorn an imperial crown. Amongst the many attractions of the National Exhibition, her gracious Majesty's three specimens of pure carbon in the celebrated Koh-i-noor and two other diamonds, are none of the least.

To the general reader the following particulars of the "Mountain of light," (Koh-i-noor) may possess interest.

The Koh-i-noor has no ordinary history, having frequently changed owners, either by the fortunes of war or intrigue, and is now little more than a third of its original weight, being reduced, by the unskilfulness of Hortense Berghere, a Venetian lapidary, from 800 to 279 carats. Its original value was estimated at $3\frac{1}{2}$ millions; it is now estimated at only half a million, for diamonds rapidly increase in value with size. It first received notice when belonging to the Mogul Princes, and was obtained by Nadir Shah when he plundered Delhi, to the extent, it is said, of 40,000,000*l.* On his assassination it disappeared for a time, until Ahmed Shah's time, and it passed from his successor, Shah Soojah, to Runjeet Singh, on whose death it remained at Lahore until it was taken by the British during the last Sikh war, and is now exhibited in Great

Britain's Industrial Palace. It is not now the largest diamond known, although originally it was so, as that of the Rajah of Mattan in India weighs 367 carats, or 3 ounces troy. A few other celebrated pieces of crystallized carbon are, the Empress of Russia's, weighing 193 carats, and valued at 90,000*l*., the Emperor of Austria's, weighing 139 carats, valued at 100,000*l*., and the Orleans or Pitt diamond, weighing 136 carats, and valued at 164,000*l*.

Such are the values of small pieces of carbon, as found in the diamond, but intrinsically, for national wealth, they will not bear an instant's comparison with that form of carbon which composes from 60 to 90 per cent. of coals. The former is an absorber of wealth otherwise existing; the latter is a producer of wealth throughout the world, and in this country forms the basis of our power and progress, without which the Crystal Palace had not been called into existence.

Carbon also unites with iron to form steel, and with hydrogen to form the common street gas, called carburetted hydrogen gas. Analysts tell us that the diamond and its converse, lamp black, are both pure carbon; and charcoal and coke are other well-known forms of carbon, obtained by burning them with a partial supply of air or oxygen. Coals are a compound of carbon, hydrogen, nitrogen and oxygen. Carbon is considered as the next most abundant body in nature to oxygen. In the furnace the carbon of the fuel unites with the oxygen of the air to produce heat. If the supply of air is correctly regulated there will be perfect combustion producing carbonic acid, but if the supply of air be deficient, combustion will be imperfect, and carbonic oxide produced.

Carbonic Acid Gas.

When air passes through a fire, this gas is formed by the combustion of 16 parts of oxygen and 6 parts of carbon. Its specific gravity is 1·523 that of air, and it forms 44 per cent

of lime. It is fatal to life, as exemplified in the black hole of Calcutta, when about 140 men died in one night by breathing the same air again and again until the oxygen in it had become this gas. It also extinguishes fire, as has been so ably shown this year by Mr. Gurney, forcing it into the burning Sauchie coal mine, and putting out a fire of about 26 acres area and 30 years duration.

Carbonic Oxide.

This is a colourless, transparent, combustible gas, which burns with a pale blue flame, as may be seen at times on opening a locomotive fire-box door. Its presence in a furnace is evidence of imperfect combustion, from a deficient supply of air, as it indicates that only 8 parts of oxygen instead of 16 parts have united with 6 parts of carbon, requiring as much more to produce complete combustion.

Hydrogen.

Hydrogen is the source of all common flame, although it extinguishes a light plunged into it, but in doing so takes fire itself and burns at the edge of the vessel, similar to its issuing from a gas burner, when it combines with the oxygen of the air and gives out a brilliant flame, but does not enter into the tube or burner where the air is not in contact to supply the necessary oxygen.

It is the lightest known body in nature, being 16 times lighter, for equal volumes, than oxygen, and is a permanent, yet combustible gas, giving out much heat. It was discovered by Cavendish in 1766, and being 14½ times lighter than air, it is employed in baloons. In our gas establishments it is now distilled from coal in large quantities, and combined with carbon for illuminating streets, shops, and dwelling houses. It is not itself innoxious to life, but does not support it, and

when combined with sulphur, it becomes explosive, and too frequently produces the most lamentable results in our coal mines. By passing a current of steam through a hot iron tube partly filled with filings, hydrogen gas is given off, and burns with a pale yellow flame. It also combines with oxygen to form water according to Watt's composition of that body. But the recent experiments of Payne seem to indicate that water may be decomposed by negative electricity into hydrogen, and by positive electricity into oxygen; and by both poles being applied, both hydrogen and oxygen are produced from the water, as ordinarily decomposed.

Comparative Heat of Carbon and Hydrogen.

Dulong estimates that 1 lb. of hydrogen will give out about 4·707 times as much heat as 1 lb. of carbon. In ordinary combustion there is rarely found any provision made to effectually consume the hydrogen evolved in the furnace, so that it has been usual to take the quantity of carbon in any coals or coke as the index of their heating powers. If hydrogen gas come to be cheaply evolved, or furnaces arranged to partly consume what is evolved, the theoretical and practical duty of fuel would be proportionally increased. If a unit of heat be taken as the quantity which would raise 1 lb. of water 1° Fah., 1 lb. of carbon is valued as equal to 13268 such units, and 1 lb. of hydrogen as equal to 62470 units, or 4·7 to 1 of carbon. In ordinary coal fires of engines the air is only admitted by the fire grate, and after passing through the fire, is consequently unfitted to totally consume the hydrogen gas evolved, which may thus pass off as lost heat, and what portion may be consumed will scarcely balance the heat necessary to its production.

Heat from Combustion.

This is variously estimated by different authorities. Des-

pretz gives the following values on lbs. of water raised 180° by 1 lb. of each fuel.

1 lb. of		Lbs. of water from 32° to 212°
Hydrogen	heat . . .	236·4
Olive oil	,, . . .	90 to 95
Ether	,, . . .	80
Pure charcoal	,, . . .	78
Wood charcoal	,, . . .	75
Alcohol	,, . . .	67·5
Coals	,, . . .	60
Baked wood	,, . . .	36

Process of Combustion in a Furnace.

For raising steam the process of combustion consists in evolving and completely consuming the combustible elements of either coal, coke, or other fuel employed, to produce heat, which may be divided into four different stages of the process:

First stage.—Application of existing heat to evolve the constituent gases of the fuel. In coals this is principally carburetted hydrogen.

Second part.—Application or employment of existing heat to separate the carbon from the hydrogen.

Third part.—Further employment of existing heat to increase the temperature of the two evolved combustibles, carbon and hydrogen, until they reach the heat necessary for combination with the oxygen of the air. If this heat is not obtained chemical union does not take place, and combustion is imperfect.

Fourth and last part.—The union of the oxygen of the air, with the carbon and hydrogen of the furnace in their proper equivalents, when intense heat is generated by the exchange of the electrical heat in each, and light is also given off from the ignited carbon. Sir H. Davy estimated this heat as greater than the white heat of metals.

In the first three stages of combustion heat is absorbed by the fuel, and only in the last stage of the process is that absorption replaced with greatly increased effects.

When the chemical atoms of heat are not united in their proper equivalents, then carbonic oxide, carburetted hydrogen and other combustible gases escape invisibly, with a corresponding loss of heat from the fuel. When the proper union takes place then only steam, carbonic acid and nitrogen escape, which, being the products of perfect combustion, are all incombustible, and also incapable of supporting combustion.

The principal products therefore of perfect combustion are :

Steam,	invisible and incombustible.
Carbonic acid,	invisible and incombustible.

The products of imperfect combustion are :

Carbonic oxide,	invisible but combustible.
Smoke,	partly invisible and partly incombustible.

Steam is formed from the hydrogen gas given out by the coals combining with its equivalent of oxygen from the air, in the ratio of 2 volumes of hydrogen to 1 of oxygen, or by weight as 1 to 8, as already explained.

Carbonic acid is formed from the carbon of the coals combining with its equivalent of oxygen from the air, in the proportion of 2 volumes of oxygen to 1 volume of carbon, or by weight, as 16 to 6.

Carbonic oxide is formed from the carbonic acid first produced, receiving another volume of carbon in passing through the fire, which last volume of carbon is unconsumed, and forms the combustible carbonic oxide, whilst carbonic acid, having had its carbon consumed, is incombustible.

Smoke is formed from the hydrogen and carbon which have not received their respective equivalents of oxygen from the air, and thus pass off unconsumed. The colour of the smoke depends upon the carbon passing off in its dark pulverized state, but the quantity of heat carried away is not

dependent upon the carbon alone, but also upon the invisible but combustible gases (hydrogen and carbonic oxide), so that whilst the colour may indicate the amount of carbon in the smoke, it does not indicate the amount of heat lost; hence the smokeless locomotive may, and does unobservedly lose more heat in this way than is lost from the combustion of coals in stationary-engine furnaces.

Besides the demands of the carbon for the oxygen admitted to the furnace, the hydrogen evolved also requires its equivalent, and could this be fairly carried out in the locomotive furnace; the oxy-hydrogen light is sufficient evidence of the intense heat which would be obtained. But where there is no provision for the proper supply of oxygen to such gases it is evident that the hydrogen evolved must nearly all pass off unconsumed.

The hydrogen requires one equivalent to produce steam, and the carbon another equivalent to produce carbonic acid. Along with these two equivalents of oxygen the air contains eight equivalents of nitrogen (of no known use in combustion), also passing through the furnace, consequently requiring 10 times as much air as there are gases to be consumed. When less than the proper quantity of air is supplied, hydrogen, from its greater affinity for oxygen than carbon, will take up its equivalent for steam, leaving the carbon to pass off partly unconsumed, as carbonic oxide. An excess of air is, however, as injurious by its tendency to lower the temperature of the evolved gases below the point where the chemical union takes place, and requires to be guarded against in the well-arranged and well-managed fire place.

A practical and familiar instance of imperfect combustion is exhibited when a lamp smokes, and the unconsumed carbon is deposited in "blacks" all round it. When the evolution of carbon is lessened by lowering the wick to meet the supply of oxygen, the carbon is all consumed and the smoke ceases. What takes place with a lamp also occurs in a furnace, so that

the proper supply of air is a primary consideration, both as regards its quantity, and its mode of admission to a fire; for both affect the economical results.

In locomotive furnaces for coke the air is usually admitted through the fire grate, and before it passes through a thick body of red-hot fuel, the oxygen is either all absorbed or so deteriorated, that it is incapable of combining with the hydrogen, which thus passes off unconsumed, and may be occasionally observed to ignite at the top of a locomotive chimney, when it obtains its equivalent of oxygen from the surrounding atmosphere. Such ignition of course only takes place when the steam is shut off, as its condensation saturates or cools the gases below the temperature of chemical union.

The economical generation of heat is therefore a process entirely distinct from the use made of that heat afterwards, just as the generation of steam is an entirely different question from its employment in an engine.

Combustion may be perfect, but absorption of heat by a boiler may be inferior, and consequently evaporation of water bear a low ratio to the fuel consumed. To arrange the construction of a boiler with rapidly absorbing materials is the principle aimed at by our best boiler-makers, to obtain increased evaporative power.

The human body has been frequently compared to a furnace, and the process of digestion to combustion, and it is a correct description, for oxygen is the active agent in both processes. In placing animal food in a red-hot platinum crucible, its carbon unites with oxygen to form carbonic acid; its hydrogen with oxygen to form water; its nitrogen either escapes free, or unites with hydrogen to form ammonia, leaving behind only some salts partly soluble and partly insoluble in water.

Now in the living animal frame these processes are in regular operation.

The food is the fuel, evolving carbon and hydrogen, which, combining with the oxygen inhaled by the lungs from the

air, is burnt, and the products of combustion, steam and carbonic acid—are exhaled from the lungs. As in the experiment with the enclosed candle, so in the human body, the nitrogen of the air appears to be inhaled and exhaled without apparent alteration. The nitrogen and soluble mineral portions of the food pass off as salts of ammonia in the urine, and the insoluble portions or "clinkers" of the food require, as is well known, especially to those suffering from dyspepsia, to be as regularly cleared off as do the residue from the fire-grate.

Sir H. Davy found that he required for respiration during 24 hours, 45,504 cubic inches, or 15,751 grains of oxygen, which produced 31,680 cubic inches, or 17,811 grains of carbonic acid, of which 4853 grains were carbon. Since oxygen is only $\frac{1}{5}$ of the air, the volume of air inhaled would be $45{,}504 \times 5 = 227{,}520$ cubic inches in 24 hours. The mean carbon issuing from the lungs of an ordinary-sized man is about 130 grains per hour, or rather more than 7 ounces daily, besides what passes off by cutaneous perspiration. In a state of repose, however, Savaser found that the consumption of oxygen was only $\frac{7}{16}$ that of a state of activity: hence sleep is known to be "tired nature's sweet restorer," by its then allowing the human furnace a little rest; for it is a law, that rapid combustion is equally fatal to the iron and to the vital furnace.

The average quantity of air inhaled at once by a man is about 20 cubic inches, and as one fifth of it again leaves the lungs in a poisonous state (carbonic acid) it vitiates any confined atmosphere unless ventilation steps in to prevent injurious consequences more or less rapid—as the supply of air may be more or less imperfect.

The animal heat of combustion is about 98° Fah., and is of course slow compared to an iron furnace of 3479° Fah.; still both processes are chemically alike, and pure air is as needful a supply to the human furnace as it is an indispensable one to the locomotive furnace.

The following table of the temperature of combustion in man and other living species may be instructive.

Table No. 12.

HEAT OF COMBUSTION IN THE LIVING FURNACE.

Class.	Temp. of Atmos. Fah.	Temp. of Animal. Fah.	Class.	Temp. of Atmos. Fah.	Temp. of Animal. Fah.
Man . .	Various.	98	Crow . .	67	104
Monkey . .	86	102	Frog . .	76	77
Hare . .	80	100	Green Serpent	81½	88½
Tiger . .	80	100	Brown ditto .	82½	84½
Dog . .	80	102	Brown Adder	82½	90
Cat . . .	77	102	Shark . .	74	77
Horse . .	79	101	Trout . .	55½	57½
Ox . . .	79	102	Flying Fish .	77½	77¾
Kite . .	80	100	Oyster . .	81	81
Sparrow .	80	108	Lobster .	79¼	79
Pigeon . .	78	109	Crab . .	72	72
Hen . .	78	110	Beetle . .	76	77
Goose . .	78	106	Glow-worm .	72	73½
Drake . .	78	110	Wasp . .	74½	76

The temperature of the animal body appears to be regulated by its own internal combustion without reference to the surrounding medium. For instance, man is found to possess the same heat under all climes and temperatures supportable by the human body.

It is estimated that the heat given off by the human body in 24 hours would raise 63 lbs. of water from the freezing to the boiling point, yet the carbon thrown off from the lungs is estimated as only equal to heat 36½ lbs. of water, through the same range. The difference is supposed to be due to the action of the muscles and the nerves.

Application of Heat to produce Steam or Evaporation.

The comparative effect of heat to produce steam in a boiler depends upon the ratio of the absorbing and transmitting power to the velocity of the escaping products of combustion.

For if the velocity be greater than the absorption and transmission of the passing heat to the water, then there will be a corresponding loss of heat. In the locomotive boiler with a rapidly escaping current only from $\frac{1}{10}$ to $\frac{1}{16}$ of the absorbing surface is by direct contact at ordinary speeds of the engine, and the remainder at right angles to the escaping current of heat. At high velocities the surface of contact will be increased to about $\frac{1}{3}$ or $\frac{1}{2}$, whilst the velocity of the escaping gases will be also increased, over a decreased length of tubes. Therefore as the velocity is increased the economy of fuel is decreased, from the failure of the absorbing and transmitting power of the boilers to convey more heat in less time to the water.

The comparative heat transmitted by conduction, radiation, and convection may be tested by alternately placing a thermometer in contact with the flame of a candle, next by its side, then over the top of the flame, and noting the temperature at each of the three positions. Or if the hand be cautiously substituted where a thermometer may not be convenient, the respective differences will be sensibly indicated, and give a clear idea of the heat lost by convection, when its velocity is considerable, and the absorbing space limited. In this respect Stephenson's and England's long boilers have an evident advantage over shorter boilers, where the diameters of the tubes do not offer sensible obstruction, for the largest portion of locomotive heating surface is on the worst or radiatory portions, at slow velocities, but decreasing as the increase of velocity extends the flames through the tubes. The experiments made by Mr. G. Stephenson, many years ago, showing the comparative evaporative ratio between the fire box and tubes of an engine at rest, as 3 to 1, would scarcely apply to an engine at very high speeds, since the relative conducting or radiating surfaces are not uniform, but vary with the velocity of the engine and heating power of the fuel. With a

low velocity these surfaces might be more uniform, if the flame acted only on the fire-box.

The economical evaporation of water into steam depends therefore, first, upon perfect combustion ; and, secondly, upon the absorbing and transmitting power of the boiler.

Where these powers are equal, the effects would be in the ratio of the surfaces of conducted and radiated heat, but where unequal in the ratio of their transmitting power only. Careful management of the fire to prevent " air holes" burning through in places, a due regard to the air-admission spaces being uniform, and a steady regular supply of fuel, have considerable effects upon the economical results from any boiler. A clear level fire, kept fed by regular-sized pieces of fuel, and the fire-grate kept free from clinkers, all contribute to economy, and should be practised. To aid the fireman or driver in their duties, as well as for the higher objects of research, there should be in every locomotive boiler one glass pane in the fire door, and one in the smoke-box door, that both the fire and the state of the escaping heat might be seen, without opening either door, until such was really necessary. The chilly effect of opening the fire door in checking the production of steam is well known, and might be so far avoided whilst the experienced eye would soon detect whether combustion was or was not perfect, and act accordingly. There is no practical difficulty in doing so, for both in this country and in America it has been done by our best experimenters, and, of course, could be done in daily practice with good results. A good self-acting feeder of fuel is desirable.

Theories of Heat.

However well known may be the effects of heat, or the sensation it produces—whilst exhibiting its gentle docility in supplying the many wants of man, its destructive powers in conflagrations, explosion, or artillery ; its potent sublimity in

the thunder-storm; its awe-inspiring force in the heaving earthquake; its formidable grandeur when issuing from the volcanic safety-valves of the great globular boiler on which we live; and the immense magnitude of its former operation in forming the shell of that boiler, all proving its power and influence in creation—its real nature remains a matter of doubt, for its subtilty and extensive range of action have as yet defeated definite analysis. This may appear singular to those who have only regarded heat as a common-place agent, since it is found still determinable at 480° below Fah. zero, whilst the sun and electricity attest its concentrated energies. This intense heat and light are strikingly exemplified in the Great Exhibition, as already referred to. However, as correctly observed by a recent investigator of its phenomena,* "Every one knows the sensation of heat, though it may be difficult to describe it."

The following is a brief outline of the prevailing theories of its nature, followed by a few practical remarks on them.

There are two theories of heat which more particularly engage attention, with a third, derived from the others. The prevailing one is that heat is a fluid of so subtle a nature as to preclude any direct investigation of its nature, which fluid is called caloric. The next theory is, that heat is not a material fluid, but is the effect of motion, and its intensity regulated by the momentum of the atoms in motion. The third theory is that heat is the motion of an elastic fluid universally diffused.

Calorific Theory of Heat.

This theory assumes that heat is a material fluid called caloric, which is communicated from one body to another by conduction, radiation, and convection.

This theory is also accompanied by the doctrine of latent heat, to account for the heat contained in any body not

* Herapath.

measurable by the thermometer, and therefore difficult to analyze as a property of a material body.

Considering the prominence which the doctrine of latent heat has long borne in reference to steam, it will be necessary to fully explain it.

Latent Heat.

Latent or hidden heat is that heat which is not measurable by a thermometer. For example, the temperature of ice is 32°, but it requires 140° of heat to convert that ice into water again, which is called the latent heat of ice, because the 140° are not indicated by the thermometer.

Water kept quite still has been cooled to 5°, yet retained its liquidity, but on motion being given to it, a great portion of it suddenly became ice at the increased temperature of 32°. The difference of 27° is called the latent heat of water at 5°.

At 212° water begins to pass off into steam, but it requires the same amount of heat to be continued nearly six times as long as raised the water to 212° to convert it all into steam, which is thus called its latent heat. Taking the temperature of water as 52° we have $212° - 52 = 160°$ of heat added to the water to raise it to the boiling point, and $160 \times 6 = 960°$ usually reckoned as 1000° for the latent heat of steam under the pressure of the atmosphere, but strictly 965·7°.

Regnault found, from an able series of experiments, from 1 up to 13·6 atmospheres, the total heat of steam increase from 1170° up to 1230° Fahr., while the diffused heat decreased from 973° to 878°. The Franklin Institute found the diffused or latent heat of steam of 212° to 215° temperature from 995·3 to 1038·5°.

Motion Theory of Heat.

This theory is, that heat is an effect measured by the motion of particles having power to communicate that motion to

other particles or to other bodies. If the motion be greater in one part than in another part of the same body, the heat will be unequal, but with a tendency to equalize the temperature throughout the mass. The power to heat would be as the temperature directly and the number of particles in motion conjointly. By bringing a thermometer in contact with a body, the motion would be communicated to the mercury, and the amount of motion be read off in the scale of parts as usual. Atoms or particles of bodies moving towards each other would unite, forming a smaller number of particles with more heat for each, but if the motion tended to separate the atoms, the temperature would decrease with the decreased momentum.

When water becomes ice, the particles combine, and the motion or temperature remains uniform, or when water becomes steam the atoms are divided with a less temperature for each, but an increased aggregate temperature.

There is, therefore, a growing disposition to regard heat as an effect similar to light, heat, space, or electricity, and that this effect arises from motion.

Theory of Heat as a Fluid in Motion.

This is merely a combination of the leading features of the calorific and motion theories, evidently based on the idea so natural to all finite minds, that by some finite agent the effect of heat might be accomplished. This theory regards heat as a fluid in vibratory motion capable of producing all the known results or phenomena attending the evolution of heat.

It differs from the motion theory by regarding the fluid as material, but agrees with it in all other points as to the effect of motion in developing heat. The remarks, therefore, on the motion theory will apply to this one, excepting the materiality of the agent, which is the difficulty required to be solved—whether heat is or is not a material body.

Remarks on Theories of Heat.

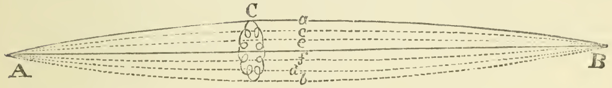
To an ordinary observer there is a difficulty in reconciling the doctrine of latent heat with the simple laws of nature, yet it is no ordinary matter to differ from the many able men who have supported this doctrine. A conviction however that as regards steam it is untenable, leads to the following remarks, being submitted with every deference to those who take an opposite view.

The usual definition of "latent" is *hidden*, and that the heat in any body which is not measurable by a thermometer is latent heat. Now it may be observed that the heat-producing properties of bodies differ greatly, and are quite distinct from their sensible heat. Thus stones from the quarry and coals from the mine, have little difference of thermometric heat, but on combination with oxygen their power of generating heat is very different. If this property of bodies evolving either heat or other body peculiar to their atomic formation be considered as a latent or hidden power, it should follow by parity of reasoning that, the effects of sound, or light produced by a change of circumstances from any other body would be the latent power of such body. For example, a piece of artillery fired along a narrow street, produces a sound accompanied by a motion of the air sufficient to break the glass in *closed* windows, but not in open ones, which leave a passage for that motion to exert its force on the more resisting walls. Minute calculations are given to inform us that the harmonious sounds of musical instruments are the effects of definite numbers of vibrations in a second of time, that the range of these vibrations for vocal music are for a male voice from 384 to 1266, and for a female voice from 1152 to 3240; that the highest note in music (five octaves above the middle C of the piano) is due to 8192 vibrations in a second, the next C 4096, the third C 2048, and so on to 16 vibrations, as the lowest

note in music. The sharpness of the sound being due to the number of times the vibrations strike the air in a second.

Fig No. 8, shows the theory of the vibration of a violin

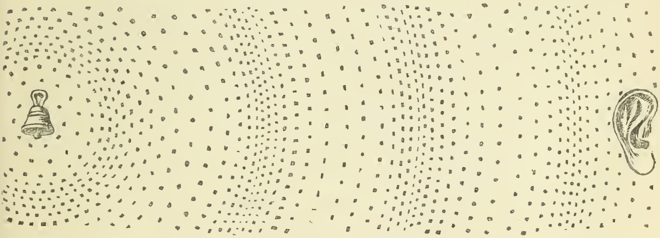
FIG. No. 8.



string, A B, which is estimated to produce 240 vibrations, if touched by the finger at a certain distance from the bow line; but if the string is pressed one half nearer to that line the sound is an octave higher, and the number of vibrations doubled, or 480 per second. The motion is, however, supposed not to be in uniform lines passing and repassing the centre lines, but more like the curved outline at C, as in Fig. No. 8.

Fig. No. 9, shows the theory of the motion produced by

FIG. No. 9.



a bell, every vibration sending a spherical wave in every direction, resembling those circular ones on the surface of a smooth sheet of water when a pebble is thrown in. The more regular these waves the more musical the sound, whilst a series of irregular waves produce a noise, but not a musical sound. A shrill whistle is due to several thousand vibrations in a minute.*

Now, if sound be the effect of motion, and the variation of

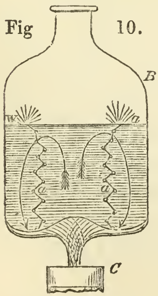
* Tomlinson's Rudimentary Pneumatics.

sounds results from the number, momentum, or delicacy of these motions, heat may be equally the effect of motion, and its quantity due to the same changes of that motion as sound. For the animating tones produced by the accomplished performer from a pianoforte, organ, or violin are equally hidden or latent, before being evoked by the impressive touch of the skilful artist, as is the heating power of fuel before ignition calls it forth.

It seems, therefore, more in accordance with the simple laws of nature, to regard heat and sound as both phenomena called forth by motion, and amenable to the same general law. The power required to produce the motion of sound, is fairly represented by the force of heat required to give a higher degree of motion or temperature, so that the power of touch, or of mechanical agency in musical instruments, has its equivalent in the quantity of heat requisite to produce certain changes of temperature in given bodies, and will be measured by the resistance to greater motion of the particular body.

It is usually advanced as a proof of the latent heat of steam that no additional heat imparted to the water increases its temperature beyond that due to the pressure on its surface, whilst six times the heat added to boil it is required to make that water into steam of the same temperature as itself. This, however, can easily be shown to be a good example of the law of equal diffusion by a very simple experiment.

Fig 10.



Water Boiling.

Let the glass phial B, Fig. No. 10, represent a boiler filled with water to W, and placed over the flame of the candle C. At first there is no visible circulation in the water, but it soon begins, and continues to increase until small globules are observed to form at the bottom from some of the descending atoms of water, and as soon as formed dart off in an irregular zigzag ascent to the surface, retaining

their spherical form. The circulation increases until ebullition commences, and larger and more numerous globules are formed, crossing each other's paths in their ascent to the top, where they expand into steam nearly 1700 times more voluminous than the water enclosing the globule. In the figure only two of these atoms of water, *a, a, a, a,* are represented, to make the process more obvious.

The questions then are, what are these globules? and, why are they in such haste to escape from the water? The reply which naturally occurs is, that these globules are ascending atoms of heat instantly caught up and surrounded by their equivalents of water, forming steam of a specific gravity about 1300 times lighter than the water, and about 1·6 times lighter than the air pressing on the water; hence their hurried irregular ascent is due to their less specific gravity struggling against the friction of the resisting water to their escape from confinement. These zigzag ascents of the little globules of steam bear some resemblance to the path of the forked lightning darting through the atmosphere, and since the friction of condensing steam issuing through small orifices is abundantly proved by Armstrong's hydro-electric boiler to produce vast quantities of electricity, is it impossible that the friction of these small globules through the water may not also evolve electricity? Armstrong's electric boiler artificially divides the condensing steam to produce friction; boiling naturally divides the water into its equivalent atoms, of separate ascent, producing a vast amount of frictional resistance to the escape of the atom of heat and its surrounding film of water. Instead therefore of the heat remaining in the water, it is evident that as soon as the water reaches the temperature of combination for steam, the atoms of heat which penetrate the boiler are separately surrounded and carried out of the water altogether, to be diffused amongst the steam, but are neither lost nor hidden. For if it only requires six atoms of heat to maintain an equal

temperature in 1700 spaces of steam, as one atom of heat did over one space of water, we have $\frac{1700}{6} = 283$ as the relative diffusion and activity of the heat in its new field.

Since condensation recalls both the heat and water to their original spaces again, it proves their diffusion, for it could not be expected that the quantity of heat which would raise the temperature of one room 10°, would equally raise the temperature of 1700 equal-sized rooms; yet such appears to be the inference drawn by those who denominate the diffused heat of steam latent or hidden heat, and its concentration as sensible heat. It will be seen, therefore, that it was a badly selected expression to call diffused heat latent or hidden, a description which is not applicable to the heat of steam. We do not usually call the heat of the air latent, yet it is in the ratio of the density of the air, as is familiar to all who have had experience with air pumps. For increasing density raises the heat, as when phosphorus is ignited by the increased heat of the air compressed in a small syringe. On expanding cooled air it rapidly absorbs heat from surrounding objects until an equilibrium of temperature is restored. Professor Smith, the Astronomer Royal of Scotland, has fully discussed these properties in an able paper on the cooling of air in Indian houses, and refers to the following tables of the heat of diffused and compressed air by Mr. Petrie, as entitled to confidence. Besides showing the effects of diffused and concentrated heat in a given volume of the atmosphere, they will be useful for reference.

Table No. 13, shows $508° - 60° = 448°$ below zero as the extreme ascertained cold, and $457{\cdot}2 - 60 = 397{\cdot}2$ below zero as the temperature of air expanded without receiving any additional heat to 1000 times its original volume. Table No. 14 shows $4572° + 60 = 4632°$ as the heat of air compressed to $\frac{1}{1000}$th part its original volume.

TABLE No. 13.

DECREASE OF THE MEASURABLE HEAT IN AIR BY DIFFUSION.

A given quantity of air expanded to vols.	Decrease of temperature from 60° Fah.	A given quantity of air expanded to vols.	Decrease in temperature from 60° Fah.
0·000	508·0	2·	104·8
1000	457·2	1·9	97·9
500	444·	1·8	90·4
200	421·	1·7	82·3
100	398·	1·6	73·7
50	370·	1·5	64·2
20	320·8	1·4	53·9
10	272·9	1·3	42·5
5	210·9	1·2	30·
3	155·2	1·1	15·9
2·5	133·7	1·0	0·0

TABLE No. 14.

INCREASE OF THE MEASURABLE HEAT IN AIR BY CONCENTRATION.

A given volume of air compressed to vols.	Increase of temperature above 60° Fah.	A given volume of air compressed to vols.	Increase of temperature above 60° Fah.
0·9	17·1	0·1	586·4
0·8	39·1	0·05	870·9
0·7	64·2	0·02	1363·5
0·6	94·3	0·01	1850·1
0·5	132·	0·005	2462·8
0·4	181·5	0·002	3524·0
0·3	251·	0·001	4572·0
0·2	360·7	0·000	

To apply these tables to any other initial temperature than 60°, add $\frac{1}{508}$ to the tabular number for higher, and subtract the same for every degree of lower initial temperature.

There has been and still continues to be considerable discrepencies between the quantities given of diffused heat by various Investigators. Even the latest and most elaborate experiments of Regnault and the Franklin Institute differ in

their exponents of that quantity. The following are a few of these discrepancies.

Table No. 15.

DIFFUSED HEAT OF STEAM BY DIFFERENT AUTHORITIES.

	Fah.		Fah.
Watt	950	Thompson	1016
Black	800	Clement	990
Southern	945	Painbow	958
Rumford	1021	Regnault	880 to 973
Ure	888	Franklin Institute	996 to 1035

The smallness of the quantities operated upon, and the delicacy of the operation itself render the slightest variation much magnified when applied to larger quantities. Their general approximation is however sufficiently near for all practical purposes, and for facility in calculation, 1000° is usually taken as the diffused heat of steam of atmospheric pressure, and 212° as the boiling point, or a total heat of 1212° Fah. Now, according to the doctrine that the latent heat diminishes as the sensible heat increases, steam at 400° temperature would only have 812° latent heat, whilst steam of the temperature of 1212° would have none, but instead of proving that the heat is latent, it proves only different stages of diffusion and concentration. Regnault's experiments show that whilst the total heat of steam is not uniform, but increasing, the diffused heat becomes less and less in quantity as the spaces occupied by a given weight of steam decreases. For as the pressure is increased the extent of motion of a given quantity is decreased, from the diminished volume of steam, so that whether at high or low pressures the temperature of an atom of heat will be inversely as the space it occupies, but not hidden.

In cooling water to the unnatural liquid temperature of 5° its sudden release from that unnatural state produces excessive motion, developing 27° of heat as its measure of restorative force, which in obedience to the general laws of nature is comparatively arrested at 32°. Now, agreeably to the laws of motion the friction of a body at rest is much greater

than that of the same body in motion, hence the comparative rest of water in ice requires a force of 140° of heat to give it the motion of fluidity; and the comparative rest of fluid water requires a force of 1000° of heat to give it the motion of steam. The heat therefore which moves the ice into water and the water into steam is the power externally applied to produce higher degrees of motion, and that motion will be the measure of the force so applied, just as the intensity of sound is measured by the musical scale from the number or force of the vibration of motion, as already referred to.

Generally as an effect of motion heat will be measured by the power of the particles in motion to propagate and communicate it to other particles. Unequal motion in any parts of a body would produce unequal temperature, tending however towards an equality of temperature. The power to heat a body would be as the temperature directly, and the number of atoms in motion conjointly, which would be communicated to a thermometer in contact with it, and be read off in the usual manner.

Atoms moving towards each other would unite to form a lesser number, with a greater amount of heat for each, or, if the motion tended to separate the atoms, they would be more numerous, but with less temperature for each separate atom. Thus we see the atoms combine, and uniform motion of 32° is obtained. When water becomes steam the atoms are separated with a less temperature for each, but an increasing aggregate temperature. For equal weights the heat of water would therefore exceed that of ice, and of steam that of water, as they are known to be by experiment.

It is further evident, that thermometers only measure the quantity of heat which is communicated to them, but not the space over which heat may be expanded, nor the aggregate heat contained in such space. In a large factory where a number of machines are put in motion by one engine, the aggregate power of that engine would not be indicated by the power required to move one machine, but by that power

multiplied by the number of machines, and other resistances. Neither does a thermometer indicate the aggregate heat in any given space, as that depends upon both the capacity and temperature combined. It is therefore difficult to realize the idea that diffused heat can be hidden heat, and some better term of expression than latent heat should be employed, if "diffused" be not all that is necessary.

The application of the term latent to the undeveloped properties of bodies is we think equally untenable as it is to steam, and more appropriate terms should be employed if they are not sufficiently conveyed to the mind by their customary names, of air, gas, coals, water, ice, or stones. Indeed, it is satisfactory to observe the growing tendency to simplify scientific nomenclature, and the readiness with which it then passes into ordinary use, where the scientific name is most simple and expressive.

Dalton found that 1 lb. of hydrogen and 8 lbs. of oxygen burnt in a close vessel produced 9 lbs. of water, and gave out as much heat as melted 320 lbs. of ice, or $35\frac{1}{2}$ lbs. of ice for each lb. of the gases; but 1 lb. of steam only melted 8·35 lbs. of ice, or less than one fourth the quantity melted by the equivalent weight of the gases. Now the thermometer does not indicate this vast difference, neither can it be the heat in the gas, since in the presence of intense cold it remains very little diminished in volume, whilst steam with very limited cold is condensed to water again. The heating power of gases is therefore like that of coals or coke, a property duly evolved under favourable combination. The light which these bodies give out may equally be designated latent, and darkness be only latent light. The sound they emit in giving forth heat and light may be equally latent. The chemical affinity, in short all the peculiar properties of bodies would thus be latent until we should cease to call them by their customary names, and only see before our eyes a mass of latents. For example, Mr. Staite has shown that heat, light, electricity, magnetism, motion and chemical affinity are all

produced in one line in the voltaic pole, where the battery represents motion and affinity; electricity in the deflection of the needle; electro-magnetism in the helex: and heat and light in the ignition of the wire in irridium lamps placed in different parts of the circuit.

There is now a growing tendency to consider heat, light, electricity, and sound as phenomena of nature, intimately associated with each other, and amenable to the same general laws.

To draw general attention to the important nature of the composition of steam these remarks on the theories of heat have been made, and those who desire to extend their information on these points, will find them ably and scientifically investigated in Herepath's Treatise on Mathematical Physics, where the motive theory of heat is elaborately supported.

COKE.

Since railway acts prohibit the use of smoke from locomotives, coals can only be sparingly used, and coke is generally employed in generating steam. Important as is this portion of locomotive expenditure, it appears to have received comparatively little attention, for the ratios of quantity and heating power of coke to the coals from which it is made are much the same in 1851 as they were found to be by Smeaton nearly 130 years ago.

Had no more progress been made in making and using steam than has taken place with coke, the success of railways would have been endangered by a continuance of the coke expenditure of 1831-2-3. In the Report on Coals for the Navy, Sir H. De la Beche and Dr. Lyon Playfair state, "The whole system of manufacturing coke is at present imperfect," and condemn the management which allows some of the valuable products from the ovens to be lost; stating, as one instance of such loss, that for every 100 tons of coke made, about 6 tons of sulphate of ammonia, worth about £13 per ton., could be collected and sold. To stimulate such economy they give the following ratios of ammoniacal products in the respective coals named.

Table No. 16.

AMMONIACAL PRODUCTS IN COALS.

Name or Locality of Coal.	Amount of Ammonia corresponding to the Nitrogen contained in Coal.	Amount of Sulphate of Ammonia corresponding to the Nitrogen contained in coal.
Graigola	0·497	1·932
Anthracite {Jones, Aubrey, and Co. .	0·225	0·990
Oldcastle Fiery Vein .	1·590	6·175
Ward's Fiery Vein . .	1·238	4·808
Binea	1·586	6·741
Llangenock . . .	1·299	5·044
Pentripoth . . .	0·218	0·848
Pentrefellin . . .	Trace	. .
Powell's Duffryn . .	1·76	6·835
Mynydd Newydd . .	1·808	7·340
Three-quarter Rock Vein .	1·299	5·044
Cwm Frood Rock Vein .	1·347	5·232
Cwm Nanty Gros . .	1·919	7·448
Resolven . . .	1·675	6·505
Pontypool . . .	1·639	6·364
Bedwas	1·748	6·788
Ebbw Vale . . .	2·622	10·182
Porthmawr Rock Vein .	1·554	6·033
Coleshill	1·785	6·930
Dalkeith Jewel Seam .	1·214	0·471
Dalkeith Coronation .	Trace	. .
Wallsend Elgin . .	1·712	6·647
Fordel Splint . . .	1·372	5·327
Grangemouth . . .	1·639	6·364
Broomhill . . .	2·234	8·674
Park End, Lydney . .	1·477	9·617
Slievardagh (Irish) . .	0·279	1·084
Formosa Island . .	0·777	3·017
Borneo (Labuan kind) .	0·977	3·771
„ 3 feet seam . .	1 132	4·620
„ 11 „ . .	0·813	3·158
Wylam's Patent Fuel .	2·040	7·920
Warlich's „ . .	Trace	. .
Bell's „ . .	0·983	3·818

Besides these products there are also much heat and much hydrogen gas evolved during coking, which are seldom turned to any profitable account. Of late years several iron works employ the escaping gases from their furnaces with economical results, and at Dundyayvan Iron Works Mr. Budd states the saving to be at least 8 per cent. In cooling coke in the ovens there is also a considerable quantity of pure hydrogen produced from the decomposition of the water by the intense heat of the oven. It is at least worth a trial to determine the commercial value of collecting such products of the coke furnace, for what iron companies do railway companies could also do, and improve upon.

The best process of manufacturing coke is still also an open question, some engineers preferring *hard*, others *soft* burnt coke, but the preponderance of numbers is in favour of the hard coke. Our observations tend to a different result, and to induce more attention to the manufacture of coke, the following remarks are submitted, accompanied by an abstract of the three valuable reports by Sir H. De La Beche and Dr. Lyon Playfair, on coals for the steam navy.

The comparative term *hard* is understood to apply to coke from which all volatile matters have been expelled, and the term *soft* to refer to coke, in which a portion of these gases still remain. They apply equally to the same vertical piece of coke in the oven as to different processes of coking. The upper part would be comparatively hard, and further heat would have little to expel from it, whilst the lower part near the bed of the oven would be *softer,* and evolve a gaseous flame, by being exposed to further heat.

In the Crystal Palace may be seen some beautiful specimens of hard coke, clean, silvery-looking columnar pieces. At the base of these same pieces may be observed a darker looking portion, of less pleasing appearance than the top portion.

This darker or comparatively softer part we regard as the most economical generator of steam in locomotive furnaces,

arising from its still retaining a portion of the original gases in the coals. That hydrogen gas is more valuable in generating steam than has usually been estimated, will be shown from practical examples with coals at the Par Consols mine, where they *water* their open burning coals to give *intensity* of heat in the furnace. Many of the best locomotive drivers *water* their coke to make it "*last longer*;" and a recent patent in America is for employing steam properly distributed over the fire to promote economy of fuel. In each case it only introduces water in a finely divided state into an intensely hot fire, which decomposes it into its equivalent of hydrogen and oxygen, and thus aids the evaporative powers of the fuel. From the coking property of some coals, water could not be beneficially used with them for steaming, since it would increase the tendency to coke, and retard the generation of steam by presenting to the boiler a fire surface comparatively cold to that presented by the glowing intensity of open burning coals. This difference may be observed in a common house fire, when the poker is required to break the surface to obtain greater heat, whilst with other coals no such coking occurs, or "pokering" the fire is required. The blacksmith's forge is an every-day instance of wetted coals producing a very superior fire to coals in their ordinary state where intensity of heat is required in the centre of the fire, and not to radiate externally against a boiler or other object. Whatever evaporative benefit may be derived from such introduction of water will arise, it is evident, from the gases evolved, and shows how very desirable it is that, as far as practical, coking should aim at retaining and not expelling such gases.

We are aware that it is usually held that the portion of water in coals, varying from 1 to 2 per cent., and that absorbed by coke, varying from 1 to 7 per cent. is not only a loss of weight, but also requires part of the remaining fuel to evaporate such water. That it would be injudicious to purchase wet fuel—also that such wetted fuel might sensibly retard

the lighting of a fire, is evident; but it is also evident that if a small per-centage of water can be converted into hydrogen and oxygen, they will be more valuable than an equal weight of either coals or coke; for in coke they would partly re-supply the gases expelled during the process of making, and add to those in coals, thus fairly accounting for the benefit said to be obtained in practice.

Unless urged by a strong draught, nearly all the forms of pure carbon burn badly. The diamond long resisted the action of heat until Lavoisier succeeded in fusing it, and showed it to be pure carbon.

Coke also requires a strong draught to promote its combustion. Lamp black in certain states ignites spontaneously in casks, but even on being exposed to the air it presents only the appearance of a number of minute sparks, with little heat and no flame. The least admission of air to spontaneously ignited coals, however, produces immediate conflagration, not unfrequently leading to serious consequences. Now, if the process of coking could be so far perfected as to retain a considerable portion of these combustible qualities of coals, and only expel the carbonaceous smoky portion, the economy would be obvious. Peat has frequently been suggested as a fuel for locomotives, and about 11 or 12 years ago Lord Willoughby D'Eresby, so well known for his promotion of industrial experiments, had some peat tried in the Hesperus locomotive, on the Great Western Railway. This engine was of Hawthorn's patent return-tube construction, and required about one third more peat than coke with equal draughts. This peat, however, did not appear at all equal in quality to the best hard black peat of the border districts of England and Scotland, being more like that brown turf cut immediately below the surface of some deep mosses; for peat, like coals, varies in lighting and heating properties. Mr. Vignoles has also interested himself in the same field, and the peat companies now forming are also directing their attention to the

various chemical and useful properties of peat and peat charcoal for heating purposes, with what results remains to be decided, as opinions are divided on its economical merits.

The gauge contest, which so rapidly promoted locomotion, also afforded some information on the economy of hard and soft coke.

During the trials of locomotive engines under the sanction of the Gauge Commissioners, the rival interests of powerful companies were brought into action, and the least point of seeming advantage of load, gradient, wind, or coke was carefully noted on both sides.

The Newcastle or Durham coke principally used on the northern railways bore a high name for its evaporative powers and durability, whilst the Welsh coke used on the Great Western Railway had only a local character inferior to the northern coke, and a claim was made for an equivalent allowance for this supposed difference.

After these trials were over the question was practically tested in the broad-gauge engines, ending contrary to anticipation in favour of the softer Welsh coke, as regarded *time* and *load*, with draughts suited to each variety. It was found that the blast pipe used for Welsh coke was too large, and the draught too little for the Newcastle coke, and the engines failed to keep time until the blast pipe was made less. This of course increased the draught and promoted the combustion of the coke, but it introduced the greater evil of increased resisting pressure against the acting pressure on the piston, leaving a balance in favour of the Welsh coke for equal loads at equal velocities by equal quantities of coke. Of the Welsh coke, the softer burnt was likewise found the best, and produced the best results in a locomotive boiler. An annoying instance of this occurred when the power of a particular engine was to be tried. The more beautiful looking upper parts of the coke were selected to fill the tender, and the trial proved a failure for want of steam. The rejected portion of

the coke, supplied to an engine for ordinary duty, produced a contrary result.

In Lancashire again, a contrary opinion was arrived at, and the inability of coke to resist the action of a hard-coke blast was assigned as a reason for its inferiority to harder coke, although it is clear that if this coke could have generated even less steam with a larger blast pipe than the hard coke with a small one, the effective power of the engine to draw a load might still have been equal. For every pound of resisting pressure taken away gives more than a corresponding advantage to the acting pressure, since there is less steam to escape for an equal amount of tractive power given out; hence, with the present construction of locomotives, it is always a desideratum to use the largest possible blast pipe. The harder the coke, the more is such an object frustrated. Coke, like coals, varies considerably in its heating powers, requiring the draught and process of combustion to be carefully attended to for each, so as to evolve the best results. Mr. Wood states, that, as compared to the Hutton and Worsley cokes taken as 100, the practical values of six other varieties not named were respectively, 76·3, 80·3, 81·7, 89, 90, 90·1, as tried, it would appear, under similar circumstances, which however might not be a fair trial for the peculiarities of each coke, since the tenderness above referred to was stated as one cause of inferiority. The coke column in the annexed tables will show the per-centage of hard coke in different coals as determined by careful experiments.

The proper regulation of the blast to the coke employed is very essential to economy. To produce the chemical equivalent of perfect combustion it requires by weight about 2·66 lb. of oxygen for each pound of carbon. Since $\frac{4}{5}$ of the air is nitrogen it requires 60 cubic feet of air to produce 1 lb. of oxygen; therefore an engine consuming coke equal to 25 lb. of carbon per mile would require $25 \times 2{\cdot}66 \times 60 = 3990$ cubic feet of air to pass through the furnace during the time

of running one mile. It is this vast quantity of air required which renders the blast-pipe necessary, though it absorbs power varying at high velocities from 25 to 30 per cent. of the working power of the steam. A larger supply of air is, however, required practically to meet the loss from various causes. It is stated that during the steam-coal investigation no combustible gases escaped up the chimney, but, on the contrary, much free oxygen, rather a singular result.

This experimental boiler had a "split" flue, a class which has usually an "eddy" favourable to the retention of the cold air or gases, and air admitted at the back of the grate might thus pass away uncombined, and form a portion of the gases ascending in concentric or other separate circles of their own. There is however, this difficulty; if the combustion was perfect the absorption was less perfect by 20 per cent. than a larger boiler of the same class at the Par Consols mine.

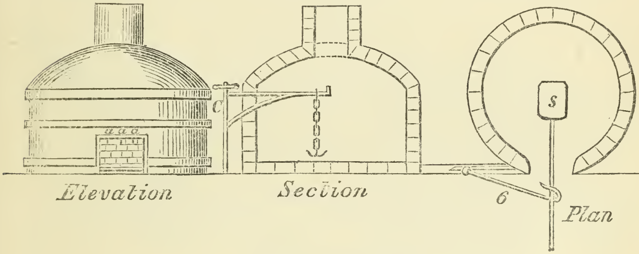
Be this, however, as it may with stationary boilers set with split flues, in locomotive boilers there is evidently much combustible gas passing off, since it readily ignites either in the smoke-box, or at the top of the chimney when air is supplied. To economize the consumption of these escaping gases Mr. Deurance introduced a gas fire-box between the coke fire-box and the tubes, making a double fire-box, like those used also for coke. A series of short tubes communicated from the coke to the gas fire-box through the divisional water space, and the admission of air was regulated by valves under the control of the driver. This was, with considerable success, tried for eleven months on the Grand Junction Railway both with coke and coals mixed, and separately. The cost was from *5d.* to *6d.* per mile, including all repairs for the regular passenger traffic, of which particulars will be given in their place. Even without such a plan benefit is found to arise from admitting air occasionally by the fire-door according to the state of the fire and the height of the door from the level of the fire surface, but uniform admission is

detrimental, and therefore it requires to be carefully regulated to produce perfect combustion.

Coke Ovens.

Like charcoal, coke was formerly made in heaps roughly covered from the air, but furnaces or ovens are now employed for that purpose. These ovens are of various forms, but it is not so much the form as the proper admission of air to the coking coals which is of importance. With a well-regulated supply of air there is not found to be any marked superiority in the most costly ovens over the cheaply constructed circular oven of which Figs. Nos. 11, 12, 13, show an elevation section,

Fig. No. 11. Fig. No. 12. Fig. No. 13.



Circular Coke Oven.

and plan. They usually hold about five or six tons of coals, and the air is admitted by the doorway at *a a a*, which is finally closed as required and luted with clay. When the process of coking is completed the brick-built door is taken down and water injected into the oven to cool down the coke. On this being done, the coke is removed by the crane C, and the large iron shovel *s*, from the oven, which is then ready to be filled again. A number of these ovens may be erected in one cluster, and connected with a central chimney, as is done by Messrs. Cory, New Barge Wharf, London.

Church's circular ovens were on the same general plan, but with a series of air passages below the coke bed, but not in contact with the coke. When the coking process was complete

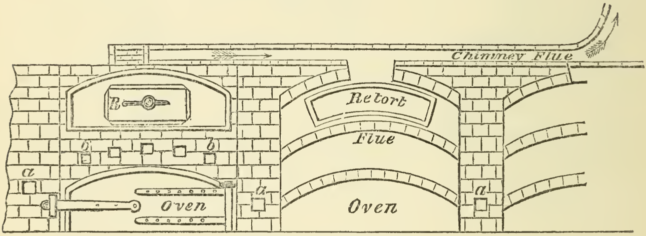
these passages were opened, to admit a current of cold air to aid in cooling down the hot coke, which was effected by carefully excluding all air from the oven without the use of water. Coke so made was therefore perfectly dry and free from hygrometric water (until it absorbed it from the atmosphere), and enjoyed considerable repute for its steaming power.

The plan of cooling with water is now generally preferred, and when done in the oven there is a better return of large coke than when drawn out hot and cooled outside the oven.

Cox's patent oven is arranged to make both coke and gas at one time, as seen in Fig. No. 14.

Fig. No. 14.

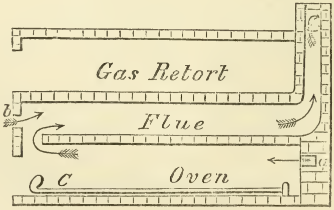
Cox's Oven.



Elevation Section.

In this oven the air is admitted by the side passages *a a*, passing along the brick work and opening into the back of the oven, as seen in Fig. No. 15. By this arrangement the air is

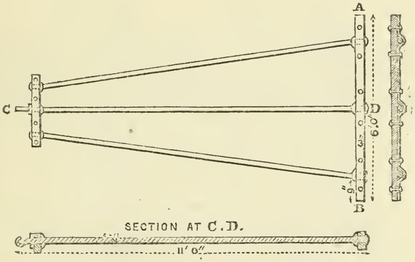
Fig. No. 15.



Longitudinal Section.

heated before it comes near the coking coal, and passes by the flue to the chimney, as seen by the arrows. When gas is required a retort R is placed in the upper arch, which is acted upon by the escaping heat of the oven. For coke alone the upper arches might be dispensed with, and the chimney placed at the front instead of the back, which would reduce the cost of erection without impairing the quality of the coke. *b b* are eye holes for observing the process of coking by the escaping products of combustion, and also for admitting air to promote the draught, as may be required. The coke is drawn out hot on the "Cradle" C., Figs. No. 16, 17, which show the

Figs. 16 and 17.



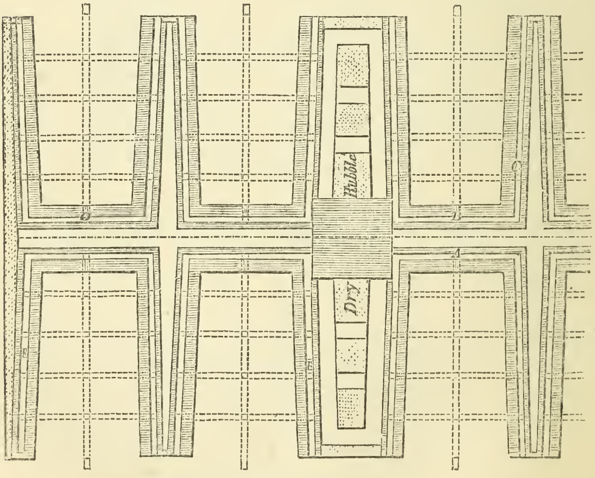
plan and edge view of this implement. It is placed on the floor of the oven, as seen in Fig. 15, and the coals put in the oven afterwards. When the coking is completed the door is opened, and a strong chain from a crab is attached to the hook of the cradle, and by the exertion of two or three men working the crab, the whole mass is drawn at once from the oven hot, and cooled with water afterwards. The coke being more friable

when hot than when cold, there is rather more small coke by this plan, than by cooling in the oven.

Amongst the most recently constructed coke ovens are those of the Bristol and Exeter Railway at Bridgewater. In them is embraced the principal improvements of late years, with modifications of both Church's and Cox's patent ovens. Church's cooling air passages are made to come in contact with the coke, to promote equal ignition, and the side-air passages have frequent openings into the oven, whilst the upper passages further regulate the admission of air, as fully illustrated in the following drawings from the "Aide Mémoire of Military Sciences."

FIG. No. 18.

Coke Oven.

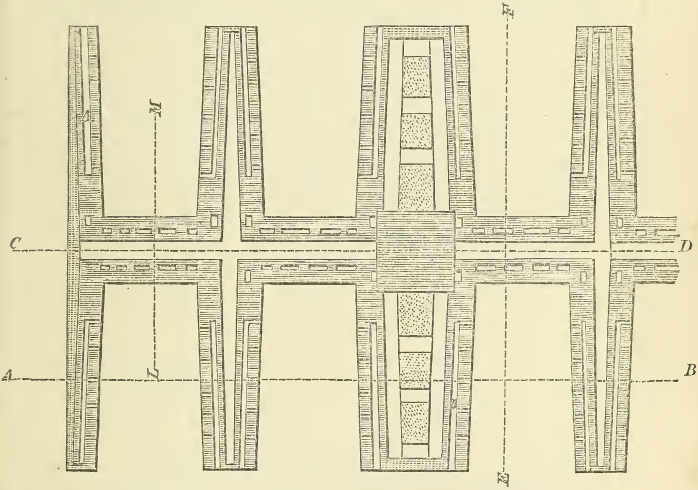


Ground or Floor Plan.

Fig. No. 18, is a ground plan of 8 coke ovens, communicating with a central chimney, showing the lowest side-air passages leading from the front, and by the transverse dotted passages underneath the coals to promote equal ignition of the whole mass at once. When this is done these passages are closed for that occasion.

FIG. NO. 19.

Coke Oven.

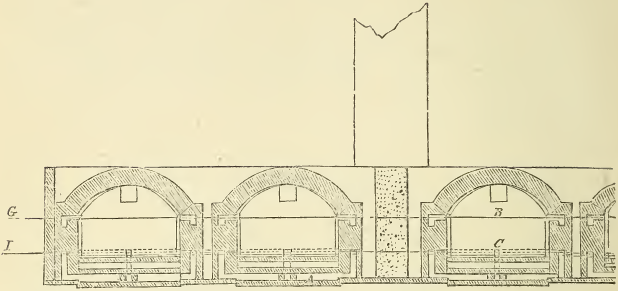


Plan at Air Passage.

Fig. No. 19, is a plan at the upper air passages for regulating the supply to the burning fuel. The side openings introduce the air so as to distribute it as equally as possible above the burning mass. The spaces parallel with the chimney between the ovens are filled up with dry rubble, as shown in both plans.

FIG. No. 20.

Coke Oven.

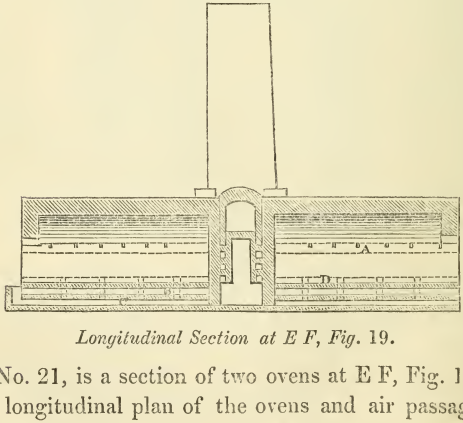


Transverse Section at A B, Fig. 19.

Fig. No. 20 is a section, at A B of Fig. 19, showing the vertical construction of the ovens, air passages, side openings, lowest air passages, and central openings, leading into the flue which connects them with the chimney.

FIG. No. 21.

Coke Oven.

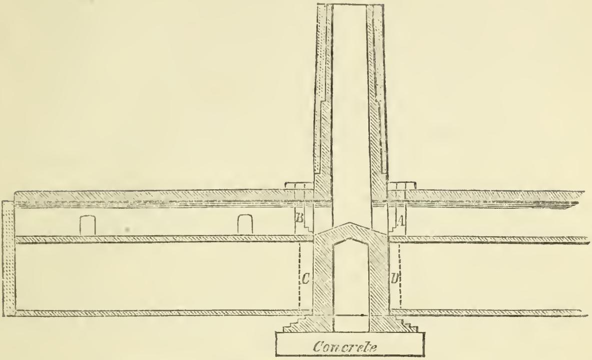


Longitudinal Section at E F, Fig. 19.

Fig. No. 21, is a section of two ovens at E F, Fig. 19, showing the longitudinal plan of the ovens and air passages, with the manner of their junction at the back.

FIG. No. 22.

Coke Oven.

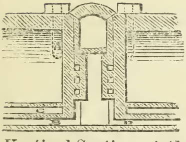


Longitudinal Section of Oven and Chimney Flues.

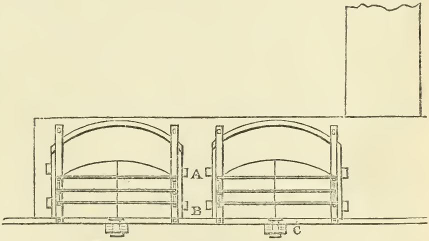
Fig. No. 22, is a longitudinal section of the oven and chimney-flue, with the dampers A B.

FIG. No. 23. FIG. No. 24.

Coke Oven.



Vertical Section at the Junction with the Chimney.



Elevation.

Fig. No. 23, is a section between the ovens at C D, showing their connection with the chimney.

Fig. No. 24, is a front elevation of two ovens, showing the external air orifices A B, with the form of the cast-iron doors and fittings.

The process of making coke with all these ovens, is to fill them with their respective quantities of coals in such rotation

as to produce a daily supply of coke. When the coke is cooled in the oven, the coals require to be lighted, but when the coke is drawn out hot, the coals then put in ignite readily by the heat of the oven. The door is then lined inside with fire bricks, and closed and luted with fire clay, to make it air-tight. Sometimes no door is used, and the opening is built up with fire bricks, leaving regulating air passages to be closed as the coking progresses. The duration of the process is from 48 to 96 hours, but is a good deal dependent on the composition of the coals, the state of the atmosphere, and the class of oven employed. When coals contain little or scarcely any sulphur, the process is slow, although an excess of sulphur is injurious to coke, and electricity has been employed to remove it before the coke was withdrawn from the oven. Still a certain amount of sulphur promotes combustion, and in this respect the Rhonda Valley coal of South Wales makes better coke than the Newport coals, which, from containing more sulphur, make superior household coals.

It is the duty of the coke burner to watch the progress of the combustion by the eye-holes for that purpose, and to regulate the admission of air accordingly. When scarcely any flame can be observed to pass from the heated mass of fuel the air is altogether excluded for some time before the oven is ready to be "drawn," or "cooled," as the case may be.

Since, therefore, even with the most carefully arranged air passages, much depends upon the care of the burner, there exists, as previously remarked, an opinion amongst experienced men that with such care judiciously exercised, the cheaper class of ovens are nearly as good as the most expensive ones for all practical purposes. The Great Western Railway Company have both classes of ovens, and find no material difference in the products, either in quantity or in quality.

The Bristol and Exeter ovens yield about 13 cwt. of good coke, $6\frac{1}{2}$ cwt. of small and waste coke, and some ashes, fit for lime burners, from a ton of Cardiff coals. The coke is drawn out of the ovens hot, by a cradle similar to Cox's, Figs. Nos.

16, 17, which probably increases the comparative quantity of small to large coke.

The superior economy of coals for generating steam has led to several trials to effect that object, without evolving smoke. Gray and Chanter have each especially designed fire-boxes for this purpose, and Durance has also tried it in his gas fire-box referred to. Whilst therefore ingenuity continues to be directed to obtain this object, there is no reason to doubt its ultimate success, when coals either in union with coke or not may be profitably employed in railway engines. From the high ratio of carbon in anthracite, and its almost smokeless combustion, it would appear well suited for locomotive purposes, more especially as it also combines combustible gases, and requires a draught similar to coke. The following abstract of the properties of various coals and anthracite will therefore supply desirable information to the locomotive as well as to the marine engineer on these essential points in the economy of steam power.

COALS.

The preceding remarks on heat, combustion, and coke, will be rendered practically available in selecting coals for particular purposes, by the following tabular arrangement of 37 varieties of Welsh, 19 of Newcastle, 28 of Lancashire, 8 of Scotch, 1 of Irish, 8 of Derbyshire, 9 of Van Diemen's Land, 2 of Patagonian, 3 of Bornean, 6 of Chilian, 5 from different localities, and 42 of American coals, with 6 of patent fuels. With the exception of the American varieties, the 132 other varieties are abstracted from the able reports of Sir H. De la Beche, F.R.S., and Dr Lyon Playfair, F.R.S., "On Coals suited to Steam Navy," begun in 1846, and the last report issued in April, 1851. The American government had instituted a similar inquiry into coals, and a copy of their report coming into the hands of Mr. Hume, M.P., that able public man lost no time in forwarding it to the Lords of the Admiralty,

(10th June, 1845,) suggesting that a similar course should be pursued to ascertain "the best coals for the naval steamers of this country." This was promptly undertaken by the Admiralty, who on the 28th June issued instructions to ascertain how the "inquiry could be conducted with the greatest effect." To the able manner in which this investigation has been conducted in all its details, and to the lucid arrangements of the reports themselves, we are indebted for this valuable addition to our knowledge of the properties of coals generally.

In endeavouring to compress the lengthened remarks on the combustible peculiarities into a tabular form, the leading features only have been given, and there was some difficulty to convey a brief yet fair impression of the text. It has however been attempted, with every desire to do impartial justice in a matter so important to the public, and to each coal-mine proprietor.

The properties sought to be determined by these experiments were, briefly, 1st. Evaporative value; 2nd. Mechanical structure; 3rd. Combustible character; and 4th. Chemical composition.

Evaporative Value.

To Smeaton we believe is due the merit of the first systematic attempt to define the comparative effect of different coals. In 1769 he constructed an experimental engine, having a cylinder nearly 10 inches diameter and 3 feet stroke. The boiler consumed 55 lbs. of coals per hour, and evaporated 6·14 lbs. of water under a pressure of 7·8 lbs. per square inch for each pound of coals.

Taking the Halston coals from Yorkshire as evolving an evaporative power of 100, he found the useful ratio of the others used by him as under—

Halston . .	100	Welsh . . .	110
Berwick Moor . .	86	Newcastle . .	120
Middleton . .	110	Cannel . . .	130

Coke $\frac{5}{6}$ of that of the coal it was made from.

The quantity of coke to coals he found about 66 per cent., or nearly the same as at present. Although recent investigations have placed the Welsh coals at the top of the practical evaporative test, yet these early experiments bear ample evidence of the care with which they had been made. Under his best boilers Smeaton found 7·88 lbs. of water by 1 lb. of coals, from 212°, as the evaporative value of Newcastle coals. Watt's improved boiler gave 8·62 lbs., and this was long considered the standard till the Cornish engineers gradually increased it to 10·74 lbs. in 1840, and in 1846 to 12·89 lbs. of water evaporated by 1 lb. of coals.

Dr. Ure gives the heating power of 1 lb. avoirdupois of different fuels as under—

1 lb. of	Heats water from 52° to 212°	Evaporates water from 212°	Weight of air to burn 1 lb. of the fuel.
	lbs.	lbs.	lbs.
Dry wood . .	35	6·36	5·96
Ordinary wood .	26	4·72	4·47
Wood charcoal .	73	13·27	11·46
Coal . . .	60	10·90	9·26
Coke . .	65	*18·88	11·46
Peat charcoal .	64	18·63	9·86
Peat . . .	30	5·45	4·60
Hydrogen gas .	76	13·81	14·58
Oil . . .	78	14·18	15·00
Wax . . .	78	14·18	15·0
Tallow . .	78	14·18	15·0
Common alcohol .	52·6	9·56	11·6

Mr. Wicksted gives the following comparative ratios of practical or realized evaporation and prices at London Bridge. The

latter now requires modification, to the extent seen in the last column.

Name of Fuel.	Water evaporated from 52° by 1 lb. of fuel.	Cost per ton at London Bridge.		Sept. 1851.	
	lbs.	s.	d.	s.	d.
Welsh, best	9·493	17	11	21	0
Anthracite	9·014	17	0	21	0
Newcastle, best small . . .	8·524	16	1	16	6
,, average . . .	8·074	15	2¾	14	9
Welsh, average	8·045	15	2¼	20	0
Gas Coke	7·908	14	11	14	4
Half coke and half Newcastle small	7·897	14	10¼	14	0
Half Welsh and half Newcastle .	7·865	14	10	17	10
Half Newcastle and half Derbyshire	7·710	14	6½	13	9
Newcastle, average of large . .	7·658	14	5½	15	8
Derbyshire	6·772	12	9¼	12	9
Blythe Main Northumberland .	6·600	12	5½		

The value given here for anthracite, is, however, much less than that found by Messrs. Josiah Parkes, and Charles Manby, of the Institution of Civil Engineers, in 1840, from a series of experiments made on anthracite as a steam fuel. With a boiler, having 340 square feet of heating surface the result gave 13·48 lbs. of water as the evaporative value of 1 lb. of the fuel, compared with 11·89 lbs., the then highest recorded duty of a Cornish boiler, having 961 square feet of heating surface, or 13 per cent. in favour of the anthracite with a small boiler. What the difference would have been in boilers of equal heating areas they had not the means to decide, but considered 13 per cent. as the minimum difference of value between anthracite and the best Welsh coals.

The subject was one of growing importance, and under the sanction of the Government, it has now been ably investigated in the following manner.

The evaporative value was arrived at by taking the mean of three separate days' trials with each fuel in a small Cornish boiler 12 ft. long, 4 ft. diameter, with inside flue of 2 ft. 6 in.

diameter and flat ends. The fire was placed in one end of this flue, and the current of heated gases returned by "split" flues round each side of the boiler to the front, where they united and passed under the boiler to the chimney. During two of the trials the pressure on the safety valves was 1 lb. per square inch, and usually 3 lbs. during the third trial.

As the comparative weight to bulk of water varies with its temperature, the necessary corrections were made by the following table, which shows a difference of 85·6 lbs. between the temperature of 70° and 212° in the actual quantity of water in the boiler.

TABLE No. 17.

Temperature of Water, Fahrenheit.	Ratio of apparent to real Weight.	Actual Weight of Water in Boiler when filled to Normal Point.	Difference between actual and apparent Weight.
°		lbs.	
70	1·0000	4730·000	0·000
80	0·9996	4728·108	1·892
90	0·9992	4726·216	3·784
100	0·9987	4723·950	6·050
110	0·9983	4721·960	8·040
120	0·9979	4719·097	10·903
130	0·9974	4717·795	12·205
140	0·9971	4715·283	14·717
150	0·9967	4714·012	15·988
160	0·9954	4708·242	21·758
170	0·9940	4701·620	28·380
180	0·9923	4693·579	36·421
190	0·9901	4683·173	46·827
200	0·9879	4672·767	57·233
202	0·9869	4668·037	61·963
204	0·9859	4663·307	66·693
206	0·9849	4658·577	71·423
208	0·9839	4653·847	76·153
210	0·9829	4649·117	80·883
212	0·9819	4644·387	85·613

The heating effect of the wood used to light the fires was first experimentally determined, and its effect,—ascertained each trial by the following table based on Regnault's experiment,—was deducted from the total evaporation of both wood and coals.

Table No. 18.

SPECIFIC AND DIFFUSED HEAT OF WATER AND STEAM FROM 32° TO 446° FAHR.

Air Ther. Cent.	Mercurial Cent.	Number of Unities of Heat abandoned by one kilo. of water in descending from T to 0°.	Air Ther. Fah.	Mercurial Fah.	Number of Unities of Heat contained in one pound of water at T°.	Mean specific Heat of Water between 0° and T cent. or between 32° and T Fah.	Specific Heat of Water from T to T + *d* T.	Latent Heat of Steam saturated to the temperature T.	
								Cent.	Fah.
°	°		°	°					
0	..	0·000	32	..	32·000	..	1·0000	606·5	1091·7
10	..	10·002	50	..	50·003	1·0002	1·0005	599·5	1079·1
20	..	20·010	68	..	68·018	1·0005	1·0012	592·6	1066·7
30	..	39·026	86	..	86·046	1·0009	1·0020	585·7	1054·2
40	..	40·051	104	..	104·091	1·0013	1·0030	578·7	1041·6
50	50·2	50·087	122	122·36	122·156	1·0017	1·0042	571·6	1028·9
60	..	60·137	140	..	140·246	1·0023	1·0056	564·7	1016·4
70	..	70·210	158	..	158·381	1·0030	1·0072	557·6	1003·7
80	..	80·282	176	..	176·507	1·0035	1·0089	550·6	991·1
90	..	90·381	194	..	194·685	1·0042	1·0109	543·5	978·3
100	100·0	100·500	212	212·0	212·900	1·0050	1·0130	536·5	965·7
110	..	110·641	230	..	231·153	1·0058	1·0153	529·4	952·9
120	..	120·806	248	..	249·450	1·0067	1·0177	522·3	940·1
130	..	130·997	266	..	267·794	1·0076	1·0204	515·1	927·2
140	..	141·215	284	..	286·187	1·0087	1·0232	508·0	914·4
150	150·0	151·462	302	302·0	304·623	1·0097	1·0262	500·7	901·2
160	..	161·741	320	..	323·133	1·0109	1·0294	493·6	888·5
170	..	172·052	338	..	341·693	1·0121	1·0328	486·2	875·1
180	..	182·398	356	..	360·316	1·0133	1·0364	479·0	862·2
190	..	192·779	374	..	379·602	1·0146	1·0401	471·6	848·9
200	200·0	203·200	392	392·0	397·760	1·0160	1.0440	464·3	835·7
210	..	213·660	410	..	416·588	1·0174	1·0481	456·8	822·2
220	..	224·162	428	..	435·480	1·0189	1·0524	449·4	808·9
230	..	234·708	446	..	454·474	1·0204	1·0568	441·9	795·4

The correction for variation of temperature of the feed-water was made by the following tabular ratios.

TABLE No. 19.

Temperature. Fah.	Actual weight of an Unity of Water.	Temperature. Fah.	Actual weight of an Unity of Water.
°		°	
40	1·001464	62	1·000712
42	1·001451	64	1·000534
44	1·001439	66	1·000356
46	1·001426	68	1·000178
48	1·001414	70	7·000000
50	1·001401	72	·999763
52	1·001294	74	·999527
54	1·001196	76	·999290
56	1·001094	78	·999054
58	1·000992	80	·998818
60	1·000890		

Comparative Evaporation of different Boilers.

To determine how far the experimental boiler gave results as compared with the best Cornish boilers, Mr. Phillips went to the Par Consols mine and had 119,700 lbs. of water evaporated from 92° by 11,730 lbs. of coals, equal to 10·204 lbs. of water by 1 lb. of coals, or 11,428 lbs. from 212°.

The Mynydd Newydd experimental coals had the nearest chemical composition to those used in the above trial, and only evaporated 9·52 lbs. of water per lb. of coals from the experimental boiler, being very nearly 20 per cent. less than in the larger boilers. The ratios therefore of realized evaporation in the tables multiplied by 1·1995 will give the value for boilers of the same evaporating power as those at the Par Consols mine.

From this it will be noticed that the tabulated evaporative results are only comparative, under the same boiler and conditions, for the precise value would vary according to the merits of the particular boiler employed.

Coking Quality of Coals.

The quantity of coke in the several varieties was ascertained by subjecting a portion of them in a crucible to a white heat for several hours, and weighing the coke left in the crucible.

This useful column in the tables will be a new source of information for the selection of particular coals for coking purposes. During the experiments only one sample of locomotive coke was sent for investigation. This was made by Messrs. Cory, of New Barge Wharf, Lambeth, from Andrews's House Tanfield coals, in a plain circular oven, having a brick-built door, and the coke cooled with water in the oven, yielding about 65 per cent. of coke from the coals used. To test the practical with the theoretical effects of coking, three separate trials were made in the crucible on coals from the same mine, which gave a mean of 65·13 per cent. of coke to coals, and was regarded as satisfactory evidence of the practical return of coke by Messrs. Cory's process of producing hard coke. Although in coking the weight of the fuel decreases 35 per cent. the bulk appears to gain about 11·7 per cent. as seen in the table. In one trial under the experimental boiler with the draught increased by blowing the steam into the chimney, the coke evaporated about 20 per cent. less water for equal weights than the coals it was made from. The same increased blast was used both with the coke and coal to give comparative results, and the following statement of this trial will show the precautions taken to ensure accuracy with all the experiments.

Table No. 20.

COMPARATIVE EVAPORATION OF WATER BY COALS AND COKE UNDER THE SAME CONDITIONS.

Particulars.	Coals.	Coke.
Fire lighted	10 h. 0 m.	9 h. 0 m.
Steam up	11 h. 0 m.	10 h. 15 m.

Particulars.	Coals.	Coke.
Wood used	10 lbs.	10 lbs.
Initial temperature of water in boiler .	192°	203°
Temperature of water in tank . .	50° mean	50° mean
Barometer	29·7 mean	29·65 mean
Extremes of external thermometer . .	32°—56°	36°—56°
Extremes of internal thermometer . .	58°—68°	52°—65°
Dew point	48° mean	461 mean
Area of damper open . . .	168 in.	168 in.
Fuel consumed . . .	2119 lbs.	2184 lbs.
Ashes left	41 lbs.	94 lbs.
Combustible matter in ashes in general from about 20 to 70 per cent. averaging about 38 per cent.		
Cinder left	12 lbs.	none
Combustible matter in cinder in general, from about 20 to 80 per cent. averaging about 55 per cent.		
Clinker	42 lbs.	25 lbs.
Average soot in flues	none	none
Combustible matter in soot in general, from about 55 to even 90 per cent. averaging about 70 per cent.		
Water evaporated . . .	17895 lbs.	15275 lbs.
Water evaporated from 212° by 1 lb. . .	9·91 lbs.	7·91 lbs.
Burnt per hour per square foot of grate .	12·4 lbs.	12·84 lbs.
Duration of Experiment . . .	34 h.	34 hours
Specific gravity	1·264	
Mean weight of 1 cubic foot . .	52·1	30·
Economic weight per 1 ton . . .	42·99	74·66
Cohesive power		
Pressure of steam blowing off . . .	3 lbs.	3 lbs.
Evaporation per hour . . .	526·3 lbs.	449·2 lbs.
Fuel per hour	62·3 lbs.	66·2 lbs.

* The per-centage of combustible matter in the ashes, cinders, and soot, is not from these experiments, but an average for general reference.

From this table it is seen that 1 lb. of coals evaporated 9·91 lbs. of water and 1 lb. of coke only 7·91 lbs. or 20·1 per cent. less than the coals. The quantity evaporated in a given time was also greater by 77 lbs. per hour for the coals, amounting to 2620 lbs. of water in the 34 hours' trial.

The increased draught also increased the evaporative results of the coals $5\frac{1}{2}$ per cent. over the previous trial with the ordinary flue draughts only. The evaporative-*power* column includes the estimated loss from the unconsumed combustible matter in the residue. The *realized* column is what was actually obtained during the trials.

Smeaton, it has been remarked, found a loss of $\frac{1}{6}$ of steam-generating power from coke, or 16·7 per cent. and 34 per cent. of loss in the manufacture, being a near approximation to the data found from these experiments.

Mechanical Structure.

The general appearance of the coal was noted, and its comparative bulk to weight for stowage was ascertained by filling a box of 6 cubic feet capacity, with each variety tried, and carefully noting the weight per cubic feet. This weight multiplied by the realized ratio of evaporation per lb. gives the evaporative power in 1 cubic foot of the particular coals.

The cohesive property was found by placing 100 lbs. of suitable sized firing pieces which would not pass through a sieve of 1-inch mesh, in a vertical wooden cylinder, 3 feet diameter and 4 feet high. This cylinder had internal angular shelves, which on its being turned round on its axes, carried the coals upwards and let them fall to the bottom, which more or less broke them according to their natural cohesion. Each variety was subjected to two trials of 50 revolutions each time, and then the mean number of pounds of coals which would not pass through the 1-inch mesh sieve is given in the tables as the comparative cohesion per cent. to resist ordinary attrition.

The ordinary hygrometric water in coals was determined by drying them at a temperature of 212°, and has been placed under this heading as more allied thereto than to chemical union, that more extended observation on the effect

of such water from fuel on the practical results might be noticed.

Combustible Character.

The combustible peculiarities were noted from observation and analyzation of the residue arising from combustion. The ease or difficulty of lighting, the draught best suited, the rapid or slow combustion, the coking or open burning, the amount of attention from the stoker, the quantity of smoke, ashes, cinders, and clinkers, with the ratios of unconsumed combustible matter in the residue were all noted.

Of the residue, the whole per-centage is given, and the clinkers separately. Ashes are no doubt troublesome when in large quantities, but these may be approximately ascertained by the chemical analysis. Clinkers are, however, more troublesome, and fusible ones which adhere to the fire bars particularly so in obstructing the draught. In the table these are marked ad. for adhesive. In locomotive furnaces the formation of clinkers is very prejudicial to the generation of steam, and Goldsworthy Gurney, Esq., from his unpleasant experience of these effects on his common-road steam carriages, calls them "fire eaters." He mentions an experiment made by himself and Sir George Cayley, Bart., to test the effect of clinkers in retarding the generation of steam. They introduced a little lime to hasten the formation of the clinker, which soon exhibited greater effects than was anticipated, rendering it difficult to keep up the steam.

The per-centage of combustible matter in the residue varies in proportion to the quantity of small coals which falls through the grate, and generally the increase of a per-centage of residue would indicate an increased per-centage of combustible matter also, over the per-centage when the fuel was fairly consumed, and the residual matter comparatively small.

It will be noticed that the Newcastle coals so generally employed for domestic use in London are of a caking, smoky

character, which, however suitable the caking is for the house or forge fire, is not so suitable for steam furnaces. It might be worth a fair trial to ascertain whether keeping the open-burning Welsh household coals *in water* would impart that coking quality to them in the house fire which it does in forge operations, as their cleanly smokeless character and superior heating power are far more than compensation for the more easily ignited bituminous coals.

An experiment with 7 lbs. of Pyle coals in their ordinary state, and 7 lbs. wet with water, showed a decided difference on a common house fire in coking in favour of the wet coals, but was found to operate the reverse way in evaporating water, for the dry coals kept a more open fire, and evaporated 2 lbs. more water in 6 hours. A further experiment by immersing 20 lbs. of these coals in water for 24 hours showed that they absorbed no appreciable quantity of water, but that due to their wet surfaces, and when these were dry no perceptible difference in weight was detected.

Chemical Composition.

The chemical analysis was carefully made from a fair average sample of the coals as mined, checked by an analysis of pure coal from the same sample. Coals in their ordinary state contain more or less shaly, whitish, dull blackish, extraneous matter or veins of iron pyrites, besides the pure coals, which decrease the evaporative value whilst they increase the duty of the stoker and per-centage of residual matter. An analysis therefore of the pure coal, or even the specific gravity of the pure coal would be no just criterion of the practical composition or practical weight per cubic foot. The analysis therefore of the average sample only *as mined* is given under this heading, as the weight per cubic foot was given under the heading of mechanical structure.

The following Tables show the various substances found in Coals and their Ashes by analysis:—

Table No. 21.

PRODUCTS FROM DESTRUCTIVE DISTILLATION OF COALS.

Name of Coal.	Coke.	Tar.	Water.	Ammonia.	Carbonic Acid.	Sulph. Hydrogen.	Olefiant gas and Hydro-carbon.	Other inflammable gases.
Craigola . .	85·5	1·2	3·1	0·17	2·79	traces	0·23	7·01
Anthracite (Jones & Co.) . . .	92·9	none	2·87	0·20	0·06	0·04	..	3·93
Old Castle Fiery Vein	79·8	5·86	3·39	0·35	0·44	0·12	0·27	9·77
Ward's Fiery Vein .	..	1·80	3·01	0·24	1·80	0·21	0·21	..
Binéa . . .	88·10	2·08	3·58	0·08	1·68	0·09	0·31	4·08
Llangennech . .	83·69	1·22	4·07	0·08	3·21	0·02	0·43	7·28

Table No. 22.

INCOMBUSTIBLE MATTERS IN COAL ASHES.

Name of Coal.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Total percentage.
Pontypool . .	40·00	44·78	12·00	trace	2·22	0·75	99·75
Bedwas . .	26·87	56·95	5·10	1·19	7·23	0·74	98·08
Warlich's pat. fuel	25·20	57·30	6·90	trace	7·85	..	99·41
Porthmawr . .	34·21	52·00	6·199	0·659	4·12	0·633	97·821
Ebbw Vale . .	53·00	35·01	3·94	2·20	4·89	0·88	99·92
Fordel Splint .	37·60	52·00	3·73	1·10	4·14	0·88	99·45
Wallsend Elgin .	61·66	24·42	2·62	1·73	8·38	1·18	99·99
Coleshill . .	59·27	29·09	6·02	1·35	3·84	0·40	99·97

Calorific Value.

This was determined chemically and also practically, by enclosing 5 grains of finely powdered coal, with 2000 grains of litharge in an air-tight crucible, and weighing the "button" of lead melted down. The tables give the mean of three separate trials with each fuel. Estimating the heating value of carbon as 13,628, the tabular value multiplied by ·45, gives the lbs. of water which 1 lb. of each fuel should raise from 30° to 212° where the structure of the coals is favourable. As this is not always so, we have preferred the litharge value for practical reference, since the chemical value is from 10 to 12 per cent. higher on the average than the litharge value.

TABLE No. 23.—COMPARATIVE COST, MECHANICAL, COMBUS OF THIRTY-SEVEN VARIE

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Sea port.	Bulk per ton, cubic feet.	Weight per cubic foot—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
Aberaman, Merthyr	2nd sample	10s.	45·80	48·9	·41	74·	ordinary	quick	freely
,, ,,	1st sample		43·57	51·4			ord.	quick	freely
Ebbw Vale			42·26	53·3	1·34	45·	easily	ord.	clear
Thomas's Merthyr			42·26	53·	1·42	57·5	ord.	ord.	freely
Duffryn			42·09	53·22	1·13	56·2	readily	ord.	freely and clear
Nixon's Merthyr		10s.	43·32	51·7	1·22	64·5	difficultly	quick	stg. flame
Binea	7s. to 10s.		39·24	57·08	3·58	51·2	slowly	ord.	freely
Bedwas			44·32	50·5	1·28	54·	easily	ord.	freely
Hill's Plymouth Works		8s. to 9s.	43·74	51·2	1·26	64·	slowly	quick	steadily
Aberdare Co.'s Merthyr			45·43	49·3	1·40	74·5	ord.	ord.	freely
Gadly 9-ft. seam			40·87	54·8	1·44	76·	ord.	strong	stg. flame
Resolven		10s.	38·19	58·66	1·55	35·	easily	ord.	strng. open flame
Mynydd Newydd			39·76	56·33	·61	53·7	easily	ord.	cake and obs.
Abercairn			44·53	50·3	7·11	54·5	easily	ord.	cake and obs.
Anthracite, Jones & Co.			38·45	58·25	2·87	68·5	diff.	quick	inten. ht.
Ward's Fiery Vein	6s. 3d. to 9s.		39·00	57·433	3·01	46·5	easily	ord.	freely and
Neath Abbey			37·77	59·3	1·02	50·	easily	ord.	freely
Craigola			37·23	60·166	3·1	49·3	easily	ord.	freely
Gadly 4-ft. seam			43·41	51·6	1·24	68·5	ord.	strong	stg. flame
Machen Rock Vein			46·56	48·1	2·5	52·5	easily	ord.	clear
Birch Grove Craigola			43·92	51·	1·51	59·	ord.	ord.	clear and
Llynvi			42·02	53·3	1·13		ord.	ord.	steadily
Cadoxtan		6s. 6d. to 10s.	38·55	58·1	1·52		diff.		badly
Old Castle Fiery Vein	6s. 6d. to 9s.		43·99	50·916	3·	57·7	easily	ord.	freely and expl.
Vivian and Son's Mirfa		7s. 6d.	46·76	47·9	·63	54·0	easily	moderate	cake and obs.
Llangennech			39·34	56·93	4 07	53·5	ord.	ord.	slowly
Three-quarter Rock Vein			39·72	56·388	1·67	52·7	easily	strong	cake mod.
Pentrepoth			38·80	57·72		46·5	diff.	ord.	
Cwm Frood Rock Vein		9s. 6d.	40·52	55·277	1·12	72·5	ord.	ord.	smoky
Cwm Nanty Gros			40·	56·	·9	55·7	easily	ord.	moderate
Brymbo Main		6s. 8d.	47·65	47·	4·50		quickly	ord.	clear
Vivian & Son's Rock Vein		7s. 6d.	45·80	48·9	1·45	70·5	quickly	mod. qk.	cake and obs.
Coleshill		8s. 6d.	42·26	53·	4·91	62·	quickly	ord.	freely
Brymbo Two-yard		7s.	46·76	47·9	3·35	79·5	easily	ord.	clear
Rock Vawr		8s. 6d.	40·72	55·	2·33	65·5	easily	ord.	moderate
Porth-Mawr Rock Vein		9s. to 9s. 6d.	42·02	53·3	1·7	62·	easily	ord.	freely
Pontypool		9s. 6d.	40·21	55·7	1·6	57·5	easily	ord.	freely
Pentrefelin	3s. 9d.		38·85	66·166	1·33	52·7	diff.	ord.	bad his. sco.

-IBLE, EVAPORATIVE, COKING, AND CHEMICAL PROPERTIES -IES OF WELSH COALS.

-HARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Clinkers, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
-rdinary .	little .	13·3	6·5	159·9	22	198		10·75		90·94	4·28	·94	1·21	1·18	1·45	85·
-rd. .	little .	13·0	7·38	159·9	23	209	10·04	9·53								
-areful .	moderate	9·5	5·87	159·9	43	187	10·64	10·21	460·22	89·78	5·15	·39	2·16	1·02	1·50	77·5
-ttle .	little .	3·9	9·03	164·8	20	209	10·72	10·16	520·8	90·12	4·33	2·02	1·00	·85	1·68	86·53
-ttle .	none .	none	7·8	150·0			11·80	10·14	409·33	88·26	4·66	·60	1·45	1·77	3·26	84·3
-ttle .	little .	5·7	11·31	166·	38	209	10·7	9·96	511·4	90·27	4·12	2·53	·63	1·20	1·25	79·11
-ttle .		none	8·22	158·2	29	216	10·3	9·94	486·95	88·66	4·63	1·03	1·43	·33	3·96	88·10
-ttle .	little .	22·9	4·79	141·	26	197	9·99	9·79	476·96	80·61	6·01	1·5	1·44	3·5	6·94	71·7
-areful .	little .	7·5	7·01	170·3	42	195	10·18	9·75	531·6	88·49	4·0	3·82	·46	·84	2·39	82·25
-ttle .	little .	9·8	8·38	170·6	58	193	10·27	9·73	489·5	88·28	4·24	1·65	1·66	·91	3·26	85·83
-areful .	none .	6·0	17·05	170·8	27	208	10·46	9·56	517·3	86·18	4·31	2·21	1·09	·87	5·34	86·54
-areful .	little .	none	4·71	160·8	30	198	10·44	9·53	390·25	79·33	4·75	in ash.	1·38	5·07	9·41	83·9
-uch .	much .	57·2	8·28	151·7	30	208	10·59	9·52	470·69	84·71	5·76	3·52	1·56	1·21	3·24	74·8
-uch .	mod. .	20· adhes.	4·83	153·8	12	207	9·63	9·47	480·	81·26	6·31	9·76	·77	1·86	2·04	6·84
-areful .	none .	little	9·58	167·4	110	194	9·7	9·46	409·37	91·44	3·46	2·58	·21	·79	1·52	92·9
-rd. .	little .	54·6	7·44	157·3	48	178	10·6	9·40	529·9	87·87	3·93	in ash.	2·02	·83	7·04	..
-equent .	much .	19·2 adhes.	5·44	156·0	52	155	9·65	9·38	546·1	89·04	5·05	..	1·07	1·60	3·55	61·42
-rd. .	little .	30·7	9·27	160·4	25	209	9·66	9·35	441·48	84·87	3·84	7·19	·41	·45	3·24	85·5
-areful .	none .	11·6	20·54	171·2	35	202	10·73	9·29	400·	88·56	4·79	..	·88	1·21	4·88	88·23
-rd. .	little .	12·4	5·26	153·3	22	205	9·43	9·23	488·75	71·08	4·88	17·87	·95	1·37	3·85	65·2
-rd. .	little .	28·6 adhes.	9·89	166·3	17	209	9·64	9·22	507·5	84·25	4·15	5·58	·73	·86	4·43	85·1
-rd. .	little .	36·	9·07	161·2	30	202	9·58	9·19	399·5	87·18	5·06	2·53	·86	1·33	3·04	72·94
-uch .	none .	34·70 adhes.	17·63	158·	105	190	9·07	8·97	344·16	87·71	4·34	1·58	1·05	1·75	3·57	82·0
-rd. .	little .	none	6·57	157·1	87	162	..	8·94	464·3	87·68	4·89	3·39	1·31	·09	2·64	79·8
-onstant .	much .	18· adhes.	5·29	155·7	22	199	9·11	8·92	421·25	82·75	5·31	4·64	1·04	·95	5·31	67·1
-rd. .		66·4	11·04	163·3	25	203	9·2	8·86	373·22	85·46	4·20	2·44	1·07	·29	6·54	83·69
-rd. .	much .	54·3	7·36	133·1	23	218	..	8·84	486·86	75·15	4·93	5·04	1·07	2·85	10·96	62·5
-areful .	little .	80·	10·47	155·8	62	198	8·98	8·72	381·5	88·72	4·50	3·24	·18	..	3·36	82·5
-rd. .	much .	38·5	7·8	141·5	28	215	9·38	8·70	379·80	82·25	5·84	3·58	1·11	1·22	6·	68·8
-areful .	little .	23·3	5·44	148·4	27	205	8·82	8·42	404·16	78·36	5·59	5·58	1·86	3·01	5·6	65·6
-ttle .	much .	10·7	5·12	151·8	17	198	8·56	8·36	435·83	77·87	5·09	9·52	·57	2·73	4·22	55·4
-uch .	considbl.	30·1 adhes.	4·75	150·	10	209	8·19	8·08	492·5	79·09	5·20	8·34	·66	2·41	4·30	58·6
-rd. .	considbl.	39·5	7·78	130·7	22	205	8·34	8·	406·41	73·84	5·14	8·29	1·47	2·34	8·92	56·0
-ttle .	much .	19·5	5·6	147·5	17	189	7·91	7·85	441·66	78·13	5·53	8·02	·54	1·88	5·90	56·2
-rd. .	little .	38· adhes.	5·92	144·6	23	198	7·88	7·68	397·5	77·98	4·39	8·55	·57	·96	7·55	62·5
-rd. .	much .	25·9	9·54	150·5	32	193	7·75	7·53	347·44	74·70	4·79	3·60	1·28	·91	14·72	63·1
-onstant .	much .	15·	12·63	137·3	17	207	8·04	7·47	250·4	80·70	5·66	4·38	1·35	2·39	5·52	64·8
-rd. .	mod. .	28·6	27·7	152·6	127	162	7·4	6·36	247·24	85·52	3·72	4·55		·12	6·09	85·0

Table No. 24.—comparative cost, mechanical, combus

of nineteen varieties of the newcastle

NAME OF COAL.	COST, per ton, at the Pit.	Nearest Sea port.†	MECHANICAL STRUCTURE. Bulk per ton, cubic feet.	Weight per cubic foot—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	COMBUSTIBLE Light.	Draught required.	Burns.
Willington		6s.	42·1	53·2	1·11	43·	difficultly	ordinary	cakes and obs.
Andrews' House, Tanfield *		5s. 6d.	42·99	52·1	6·58		easily		cakes and obs.
,, ,, Coke			74·66	30·				strong	
Bowden Close		6s.	44·26	50·6	1·33	38·5	ordinary	ord.	cakes and obs.
Haswell Wallsend		9s. 3d.	47·25	47·4	4·08	73·	ord.	ord.	cakes and obs.
Newcastle Hartley	7s.		44·35	50·5	1·38	78·5	diff.	strong	
Hedley's Hartley			43·07	52·	1·46	85·5	easily	quick	slowly
Bates West Hartley		8s.	44·13	50·8	9·28	69·5	ord.	mod. qk.	mod. free
West Hartley Main		7s. to 7s.6d.	45·80	48·9	6·76	79·	easily	ord.	rapidly
Buddle's West Hartley		8s.	44·09	50·6	7·24	80·	ord.	mod. qk.	freely
Hasting's Hartley		7s. 6d.	46·18	48·5	7·88	75·5	easily	ord.	freely
Carr's Hartley		7s. 6d.	46·86	47·8	5·60	77·5	easily	ord.	mod.
Davison's West Hartley		7s. 6d.	46·96	47·7	6·19	76·5	easily	ord.	freely
North Percy Hartley		8s.	45·62	49·1	8·41	60·	easily	ord.	freely
Haswell Coal Company's Steamboat Wallsend		8s.	45·25	49·5	1·14	79·5	easily	ord.	freely for a time
Derwentwater Hartley		6s. 6d.	46·44	50·4	12·52	63·5	easily	ord.	rapid
Broom Hill	3s. 4d.		42·67	52·5	9·31	65·7	easily	mod. qk.	dull flame
Original Hartley		7s. 6d.	45·62	49·1	8·11	80·	easily	ord.	rapidly
Cowpen and Sidney's Hartley		7s.	46·76	47·9	10·17	74·	easily	ord.	freely

* 1 lb. of Coals with ordinary draught evaporated 9·39 lbs. at the rate of 351·2 lbs. per hour.
1 lb. ,, uneven draught ,, 9·91 lbs. ,, 526·3 lbs. ,,
1 lb. of Coke ,, ,, ,, 7·91 lbs. ,, 449·3 lbs. ,,

Newcastle Coals are said to have been first mined or "dug," during the reign of Henry III. in 1280.

BLE, EVAPORATIVE, COKING, AND CHEMICAL CHARACTERS ISTRICT COALS AND ONE SAMPLE OF COKE.

IARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
ıstant .	much .	7· non ad.	5·61	156·5	20	206	10·16	9·95		86·81	4·96	5·22	1·05	·88	1·08	72·19
:eful .	much .	3·2	4·5	155·9	40	195	9·8*	9·39 9·91	351·2 526·3	85·58	5·31	4·39	1·26	1·32	2·14	65·13
		25·6	5·4		45	203		7·91	449·2							
ıstant .	much .	6·6	5·53	158·5	28	203	9·67	9·38		84·92	4·53	6·66	·96	·65	2·28	69·69
ıch .	do. & soot	3·5	4·77	157·5	28	199	9·07	8·87	411·66	83.47	6·68	8·17	1·42	·06	·20	62·7
reful .	much .	17·0 non ad.	8·07	159·3	30	202	8·65	8·23	308·	81·81	5·5	2·58	1·28	1·69	7·14	64·61
ıstant .		14·4	11·89	151·8	33	180	8·71	8·16	300·8	80·26	5·28	2·40	1·16	1·78	9·12	72·31
tle .	much .	1·4	4·48	144·6	27	202	8·26	8·04	406·8	80·61	5·26	6·51	1·52	1·85	4·25	
l. .	much .	2·8	4·40	151·8	17	208	8·05	7·87	457·5	81·85	5·29	7·53	1·64	1·13	2·51	59·20
tle .	much .	5·9	4.82	147·7	35	202	8·01	7·82	413·3	80·75	5·04	7·86	1·46	1·04	3·85	
reful .	little .	1·7	4·59	142·8	20	201	7·96	7·77	404·5	82·24	5·42	6·44	1·61	1·35	2·94	35·6
nsider.	much .	5·0 non ad.	5·76	154·5	28	200	8·13	7·71	344·3	79·83	5·11	7·86	1·17	·82	5·21	60·63
tle .	consid. .	2·1	4·47	150·6	23	207	7·83	7·61	402·9	83·26	5·31	2·50	1·72	1·38	5·84	59·42
reful .	consid. .	7·8 non ad.	4·86	145·5	28	203	7·72	7·57	423·5	80·03	5·08	9·91	·98	·78	3·22	57·18
nstant .	much .	9·8	10·45	144·	38	184	7·85	7·48	291·8	83·71	5·30	2·79	1·06	1·21	5 93	61·38
tle .	much .	28·3	6·33	145·5	40	202	7·66	7·42	451·1	78·01	4·74	10·31	1·84	1·37	3·73	54·83
ıch .	little .	5·	3·23	126·6	44	208	7·66	7·3	397·7$_8$	81·7	6·17	4·37	1·84	2·85	3·07	59·2
tle .	much .	10·1	4·27	133·1	66	155	6·98	6·82	428·4	81·18	5·56	8·03	·72	1·44	3·07	58·22
l. .	much .	3·7	5·69	143·3	27		7·02	6·79	350·4	82·2	5.10	7·97	1·69	·71	2·33	58·59

† The duty paid on coals and coke last year was £251,547 11*s.* 7*d.*, of this £175,91 15*s.* 6*d.* was for the rt of London, and principally on "sea-borne" or Newcastle coal. The railway dues for the rest of the ıited Kingdom was only £8363 9*s.* 3*d.*

TABLE No. 25.—COMPARATIVE COST, MECHANICAL, COMBUS

TWENTY-EIGHT VARIE

LANCA

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Sea port.	Bulk per ton, cubic feet.	Weight per cubic feet—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
Ince Hall Companies, Arley	7s.	9s. 6d.	47·05	47·6	1·07	73·5	easily	ord.	cake sligh.
Haydock, Little Delf			49·88	44·9	3·19	66·5	easily	ord.	freely
Balcarres, Arley	6s.		44·35	50·5	1·86	76·	easily	ord.	freely
Blackley, Hurst			46·66	48·0	3·66	65·	ord.	ord.	freely
Ince Hall, Pemberton Yard	6s. 6d.	8s 6d to 9s 6d	46·66	48·0	2·55	75·5	easily	ord.	clear
Haydock, Rushy Park			45·43	49·3	1·89	77·	easily	ord.	freely for a time
Moss Hall, Pemberton, 4-ft.	6s.		47·35	47·3	3·32	71·5	easily	ord.	clear
Haydock, Higher Florida			45·25	49·5	6·12	74·	easily	ord.	freely for a time
Ince Hall, Pemberton, 4-ft.	6s.	8s 6d to 9s 3d	43·24	51·8	4·86	74·5	readily	ord.	clear
Blackbrook, Little Delf	6s. to 7s.		43·92	51·	5·58	61·5	easily	ord.	freely
King	8s. 6d.	15s.	44·09	50·8	2·84	78·5	easily	mod. qk.	rapidly
Rushy Park Mine	7s.		47·65	47·	11·66	67·	easily	ord.	clear
Blackbrook, Rushy Park	6s. to 7s.		40·5	55·3	5·90	80·5	easily	ord.	freely
Johnsons & Worthingtons, Rushy Park			44·8	50·	7·15	69·	easily	ord.	clear
Laffak, Rushy Park	7s 6d.		42·58	52·6	6·24	75·5	easily	ord.	clear
Balcarres, Haigh Yard	6s.	9s.	44·13	50·8	2·69	80·	easily	ord.	steadily
Haydock, Florida Vein			46·66	48·0	6·61	81·5	easily	ord.	freely for a time
Wigan, 4-ft.	5s. 6d. to 6s.	9s. to 9s. 6d.	41·94	53·4	2·69	75·	easily	ord.	rapidly
Ince Hall, Pemberton, 5-ft.	5s. 6d.	8s.	43·24	51·8	4·75	71·5	easily	strong	freely for a time
Cannel (Wigan)	10s. to 12s.	14s. to 18s.	46·37	48·3	1·01	95·	easily	ord.	freely
Ince Hall Cos. Furnace Vein	5s. 6d.	7s. 6d. to 8s.	45·43	49·3	5·33	71·5	easily	ord.	freely for a time
Balcarres, Lindsay	6s. 8d.		43·83	51·1	6·47	70·	easily	quick	stead. for a time
Caldwell & Thompsons, Rushy Park	5s. 6d. to 7s.	8s. to 9s. 6d.	47·15	47·5	4·97	76·	easily	ord.	clear
Balcarres, 5-ft.	6s. 8d.		45·71	49·	7·12	44·5	easily	ord.	freely
Moss Hall, Pemberton, 5-ft.	5s.		46·37	48·3	3·69	78·5	easily	ord.	freely for a time
Moss Hall Cos. New Mine	5s.		46.28	48·4	6·76	76·5	easily	ord.	freely for a time
Caldwell & Thompsons, Higher Delf	5s. 6d. to 7s.	8s. to 9s. 6d.	46·28	48·4	0·98	77·	easily	consid.	clear for a time
Johnsons & Worthingtons Sir John	6s.	9s.	43·41	51·6	4·62	82·	diff.	strong	slowly

...IBLE, EVAPORATIVE, COKING, AND CHEMICAL QUALITIES OF ...IES OF LANCASHIRE COALS.

...HIRE.

...HARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
...rd.	much .	·107 adhes.		162·5	22	204	9·55	9·47	487·29	82·61	5·86	7·44	1·76	·8	1·53	64·
...uch .	much .	9·6		146·6	13	197	9·26	9·13	532·91	79·71	5·16	10·65	·54	·52	3·42	58·1
...rd. .	much .	11·0 adhes.	5·68	147·0	18	205	9·09	8·83	454·1	83·54	5·24	5·87	·98	1·05	3·32	62·89
...rd. .	much .	10·8	3·74	147·9	28	192	9·00	8·81	500·8	82·01	5·55	5·28	1·68	1·43	4·05	57·84
...rd. .	much .	12·2 non ad.	4·9	150·2	13	205		8·78	461·25	80·78	6·23	7·53	1·30	1·82	2·34	60·6
...uch .	much .	7·8 adhes.	3·39	149·	12	209	8·91	8·74	461·66	77·65	5·53	10·91	·50	1·73	3·68	59·4
...rd. .	much .	7·1 adhes.	3·39	142·5	22	204	8·65	8·52	480·	75·53	4·82	7·98	2·05	3·04	6·58	55·7
...uch .	much .	13·2	3·62	148·6	9	210	8·49	8·39	467·5	77·33	5·56	12·02	1·01	1·03	3·05	51·1
...ittle .	consid.	2·1	3·52	144·3	28	193	8·45	8·34	497·39	77·01	3·93	5·52	1·40	1·05	1·09	57·1
...areful .	much .	none	3·55	143·4	33	185	8·55	8·29	440·4	82·7	5·55	4·89	1·48	1·07	4·31	58·48
...areful .	much .	47·1 adhes.	3·55	136·4	22	203	8·35	8·17	395·41	73·66	5·30	9·06	1·68	1·58	8·72	62·4
...rd. .	consid.	2·7	3·14	144·9	23	193	8·35	8·08	419·1	77·76	5·23	8·99	1·32	1·01	5·69	56·66
...areful.	little .	2·1 adhes.	2·77	151·8	20	198	8·26	8·02	481·2	81·16	5·99	7·20	1·35	1·62	2·68	58·10
...rd. .	much .	8·6	3·64	144·5	28	199	8·16	8·01	454·5	79·5	5·15	9·24	1·21	2·71	2·19	57·52
	much .	5·1	3·78	134·0	22	203	8·16	7·98	435·	80·47	5·72	8·33	1·27	1·39	2·82	56·26
...rd. .	much .	26·4 adhes.	8·34	140·8	23	207	8·23	7·9	398·3	82·26	5·47	5·64	1·25	1·48	3·90	66·09
...uch .	much .	9·	3·97	146·3	12	209	8·97	7·83	422·5	77·49	5·50	12·84	1·27	·88	2·02	54·4
...rd. .	much .	37·6	7·98	150·1	20	207	8·05	7·77	414·79	78·86	5·29	9·57	·86	1·19	4·23	60·
...uch .	consid.	20·4 adhes.	8·74	143·7	23	208	7·95	7·72	495·2	68·72	4·76	18·63	2·20	1·35	14·34	56·5
...areful.	much .	21·1 adhes.	7·84	148·7	20	194	8·06	7·70	381·1	79·23	6·08	7·24	1·18	1·43	4·84	60·33
...areful.	much .	25·3 adhes.	7·40	143·	13	211	7·84	7·47	435·21	74·74	5·71	13·52	1·53	·96	4·04	58·4
...rd. .	much .	22·3	4·93	131·	25	203	7·58	7·44	431·5	83·9	5·66	5·53	1·40	1·51	2·00	57·84
...ittle .	consid.	5·1	2·38	147·1	22	203	7·43	7·34	449·79	76·17	5·46	14·87	1·09	·91	1·50	58·7
...rd. .	much .	21·8	4·77	129·8	20		7·35	7·21	489·5	74·21	5·03	8·69	·77	2·09	9·21	55·90
...uch .	much .	31·9 adhes.	6·35	137·4	20	202	7·29	7·13	417·18	76·16	5·35	10·13	1·29	1·05	6·02	56·1
		34·2 adhes.	5·86	135·1	23	204	7·16	7·04	422·08	77·50	4·84	12·16	·98	1·36	3·16	57·7
...uch .	much .	38·6 adhes.	5·85	141·8	40	188	6·94	6·85	484·28	75·40	4·83	19·98	1·41	2·43	5·95	54·2
...uch .		34·4	9·42	119·	22	209	6·62	6·32	362·7	72·86	4·98	8·15	1·07	1·54	11·4	56·15

TABLE No. 26.—COMPARATIVE COST, MECHANICAL, COMBUSTIBL

VARIETIES OF DERBYSHIRE, EIGHT OF SCOTCH COALS, SI

NAME OF COAL.	COST, per ton, at the Pit.	COST, per ton, at the Nearest Sea port.	MECHANICAL STRUCTURE. Bulk per ton, cubic feet.	MECHANICAL STRUCTURE. Weight per cubic feet—lbs.	MECHANICAL STRUCTURE. Weight of Water in Coals, per cent.	MECHANICAL STRUCTURE. Cohesion of large Coals, per cent.	COMBUSTIBI Light.	COMBUSTIBI Draught required.	COMBUSTIBI Burns.
									DERI
Earl Fitzwilliam's Elsecar .		5s. 9d.	47·45	47·2	4·83	77·	easily .	mod. .	freely
Hoyland & Cos. Elsecar .		5s. 9d.	46·47	48·2	3·72	82·5	easily .	mod. qk.	freely
Earl Fitzwilliam's Park Gate			47·65	47·	3·08	78·	easily .	mod. qk.	freely
Butterly Cos. Portland .		6s. 9d.	47·55	47·1	7·36	89·	easily .	mod. qk.	{ free
Butterly Cos. Longley .		6s.	46·86	47·8	3·55	84·5	easily .		{ free
Staveley		9s.	44·88	49·9	8·54	88·5	easily .	ord. .	freely
Loscoe, Soft . . .	5s. to 7s.		50·0	44·8	9·76	62·	readily .	ord. .	{ freely for a time
Loscoe, Hard . . .	5s. to 7s.		48·8	45·9		86·	readily .	ord. . .	{ freely for a time
									SCO
Elgin Wallsend . .			41·02	54·6	2·49	64·	easily .	ord. .	freely
Wellewood . . .		8s. 6d.	42·58	52·6	2·77	80·	easily .	ord. .	freely
Dalkeith Coronation . .			43·36	51·66	5·3	88·2	easily .	ord. .	freely
Kilmarnock Shevington .		6s.	50·11	44·7	7·76	63·5	easily .	ord. .	freely
Fordel Splint . . .		9s.	40·72	55·0	8·4	63·	easily .	ord. .	stg. flan
Grangemouth . . .		9s.	40·13	54·25	6·42	69·7	easily .	ord. .	mod.
Eglinton . . .		7s. 4d.	43·07	32·0	10·02	79·5	easily .	ord. .	rapid
Dalkieth Jewel . .			44·98	49·8	9·7	85·7	easily .	ord. .	freely
									VAR
Slievardagh Irish Anthracite .	20s. to 25.		35·66	62·8	4·93	74·	difficultly	strong .	clear
Coleshill Co.'s Bagilt Main .		7s.	45·16	49·6	5·50	79.	easily .	ord. .	freely
Ewloe			44·44	50·4	6·83	84·	easily .	quick .	clear
Ibstock . . .	7s. 6d.		47·35	47.3	1·12	62·	easily .	quick .	clear
Forest of Dean (Lydney). .		10s. to 11s.	41·14	54·44	2·78	55·	easily .	mod. .	smoky
Conception Bay (Chili) .					13·52		easily .	ord. .	freely
									PATEN
Warlich's Patent Fuel .			32·44	69·05	·92		slowly .	ord. .	mod.
Livingstone's Steam Fuel .			34·14	65·6	1·39		difficultly	ord. .	slowly
Lyon's Patent Fuel . .			36·66	61·1	1·91				mod.
Wylam's Patent Fuel .			34·41	65·08	1·38		readily .	quick .	freely
Bell's Patent Fuel . .			34·30	63·3	·9		slowly .	ord. .	ord.
Holland and Green's .			34·56	64·8	2·18		easily .		{ freely for a time

APORATIVE, COKING, AND CHEMICAL PROPERTIES OF EIGHT
HER VARIETIES, AND SIX VARIETIES OF PATENT FUEL.
IRE.

ARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
ch		6·6	5·95	150·5	23	198	8·78	8·52	412·7	81·93	4·85	8·58	1·27	·91	2·46	61·6
ch	much	1·7	7·9	148·6	23	197	8·43	8·07	372·91	80·05	4·93	8·99	1·24	1·06	3·73	62·5
ch		none	7·60	150·6	22	199	8·24	7·92	393·75	80·07	4·92	9·95	2·15	1·11	1·80	61·7
eful	much	10·3 non ad.	4·39	155·2	22	199	8·04	7·92	487·08	80·41	4·65	11·26	1·59	·86	1·23	60·9
eful	much	10·0	6·48	150·	15	209	7·98	7·8	398·69	77·97	5·58	9·86	·80	1·14	4·65	54·9
.	much	12·6	4·78	140·4	22	207	7·40	7·26	466·2	79·85	4·84	10·96	1·23	·72	2·40	57·8
at	much	8·4 adhes.	3·36	140·2	22	208	7·99	6·88	490·06	77·49	4·861	2·41	1·64	1·30	2·03	52·8
at	much	8·5 adhes.	4·64	147·9	18	208		6·32	431·42							
.																
e	consid.	14·5	4·73	145·3	28	203	8·67	8·46	435·77	76·09	5·22	5·05	1·41	1·53	10·70	58·45
e	much	28·5	4·50	142·4	35	181	8·39	8·24	438·5	81·36	6·28	6·37	1·53	1·57	2·89	59·15
e	little	62·2	5·9	122·8	30	180	7·86	7·71	370·08	76·94	5·2	14·37	trace	·38	3·10	53·5
eful	much	6·4	3·42	151·6	17	202	7·82	7·66	470·83	79·82	5·82	11·31	·94	·86	1·25	49·3
e	consid.	3·	2·86	145·0	40	176	7·69	7·56	464·98	79·58	5·5	8·33	1·13	1·46	4·0	52·03
.	little	16·4	5·26	142·4	28	208	7·91	7·40	380·4	79·85	5·28	8·58	1·35	1·42	3·52	56·6
.	much	82· non ad.	4·03	121·6	33	186	7·48	7·37	406·2	80·08	6·5	8·05	1·55	1·38	2·44	54·94
e	little	59·5	3·92	132·1	40	193	7·1	7·08	355·18	74·55	5·14	15·51	·10	·33	4·37	49·8
US.																
eful	none	17·9	7·25	150·5	110	150	10·49	9·85	473·18	80·03	2·3	in ash.	·23	·76	10·8	90·1
.	mod.	5·7	3·92	152·	28	197	8·5	8·33	461·25	88·48	5·62	·86	2·02	1·36	1·62	55·8
eful	mod.	4·4	4·72	135·6	17	208	7·16	7·02	363·95	80·97	4·96	8·20	1·1	1·4	3·37	54·5
eful	little	14·1 non ad.	4·10	125·5	20	206	7·02	6·91	454·16	74·79	4·83	11·88	·88	1·45	5·99	50·8
.	much	2·45	4·06	129·7	20	218	8·98	8·52	487·19							
eful	much	44·5 ad.	8·48	128·1	30	208	5·96	5·72	425·							
ELS.																
eful	little	29·6	6·79	157·5	30	203	10·60	10·36	457·84	90·02	5·56	in ash.	trace	1·62	2·91	85·1
ch	little	28·2	10·95	162·7	33	194	10·57	10·03	483·95	86·07	4·13	2·03	1·80	1·45	4·45	
ch	much	38·7	6·06	156·9	38	189	9·77	9·58	409·1	86·36	4·56	2.07	1·06	1·29	4·66	
l.	mod.	59·5	7·27	144·1	35	199	9·74	8·92	418·89	79·91	5·69	6·63	1·68	1·25	4·84	65·8
at	consid.	76·1	6·7	142·6	37	201	8·65	8·53	549·11	87·88	5·22	0·42	·81	·71	4·96	71·7
ch	consid.	87·6	12·55	118·4	22	204	7·86	7·59	470·0	70·14	4·65		1·15		13·73	

Table No. 27.

SUMMARY OF THE MEAN AVERAGES OF THE COALS FROM DIFFERENT LOCALITIES.

	MECHANICAL STRUCTURE.			EVAPORATION OF WATER.			CHEMICAL COMPOSITION.						
	Bulk of 1 ton cub. ft.	Weight of 1 cub. foot, lbs.	Cohesion per cwt. of large coals.	By 1 lb. of coals. lbs.	Per hour. lbs.	Sulphur per cent.	Carbon per cent.	Hydrogen per cent.	Oxygen per cent.	Nitrogen per cent.	Sulphur per cent.	Ashes per cent.	Coke per cent.
Welsh, 37 Samples .	42·71	53·1	60·9	9·05	448·2	1·42	*83·78	4·79	4·15	0·98	1·43	4·91	72·6
Newcastle, 17 ditto .	45·3	49·8	67·5	8·37	411·1	0·94	82·12	5·31	5·69	1·35	1·24	3·77	60·67
Lancashire, 28 ditto .	45·15	49·7	73·5	7·94	447·6	1·42	77·0	5·32	9·53	1·930	1·44	4·88	60·22
Scotland, 8 ditto .	49·99	50·	73·4	7·7	431·4	1·45	78·53	5·61	9·69	1·0	1·11	4·03	54·22
Derbyshire, 8 ditto .	47·45	47·2	80·9	7·58	432·7	1·01	†79·68	4·94	10·28	1·41	1·01	2·65	59·22

* Mean of 36 samples. † Of seven experiments.

TABLE No. 28.

CHEMICAL COMPOSITION OF VARIOUS FOREIGN AND COLONIAL COALS.

VAN DIEMEN'S LAND.

Name.	Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
South Cape .	3·33	63·4	2·89	1·01	1·27	·98	30·45
Mnt. Nicholas Break o'Day	7·24	57·37	3·91	9·10	1·15	·90	27·55
Tingal . .	4·86	57·21	3·38	7·8	1·2	1·32	29·09
Jerusalem . .	3·06	68·18	3·99	5·89	1·62	1·12	19·20
Douglas River East Coast .	4·87	70·44	4·20	9·27	1·11	·70	14·38
Tasman's Peninsula	4·40	65·54	3·36	1·75	1·91	1·03	26·41
Schoten Island .	2·17	64·01	3·55	3·38	·94	·85	27·17
Whale's Head South Cape	1·72	65·86	3·18	7·20	1·12	1·14	21·50
Adventure Bay .	3·81	80·22	3·05	4·8	1·36	1·9	8·67
VARIOUS.							
Sydney, New South Wales	3·25	82·39	5·32	8·32	1·23	·70	2·04
Borneo Labuan .		64·52	4·74	20·75	·80	1·45	7·74
,, 3ft. Seam		54·31	5·03	24·22	·98	1·14	14·32
,, 11ft. Seam		70·33	5·41	19·19	·67	1·17	3·23
Formosa Island .		78·26	5·7	10·95	1·64	·49	3·96
Vancouver's Island .	7·21	66·93	5·32	8·7	1·02	2·2	15·83
Lignite, Trinidad	2·62	65·20	4·25	21·69	·33	·69	6·84
CHILIAN.							
Conception Bay .		70·55	5·76	13·24	0·95	1·98	7·52
Port Famine .	14·63	64·18	5·33	22·75	0·50	1·03	6·21
Chirique .	9·11	38·98	4·01	13·38	·58	6·14	36·91
Laredo Bay . .	16·03	58·67	5·52	17·33	·71	1·14	16·63
Talcahnano Bay.	12·43	70·71	6·44	13·95	1·08	·94	6·92
Colcurra Bay .	5·89	78·30	5·50	8·37	1·09	1·06	5·68
PATAGONIAN.							
Sandy Bay No. 1	22·68	62·25	5·05	17·54	·63	1·13	13·4
,, No. 2	22·26	59·63	5·68	17·45	·64	·96	15·64
Juan Fernandez .	6·06						

Table No. 29.

CHEMICAL ANALYSIS OF FORTY-TWO VARIETIES OF AMERICAN COALS.

ANTHRACITE.				BITUMINOUS.			
Name.	Carbon, per cent.	Gases per cent.	Ashes per cent.	Name.	Coke.	Gases.	Ashes.
Nesquehoning	86·6	6 4	7·	Hopewell Furnace . . .	88·2	11·2	4·
Le High Summit	88·5	7·5	4·	Lick Run	79·28	20·72	13·07
„ hardest . .	87·7	6·6	5 7	Queen's Run . . .	78·28	21·2	2·07
Tamaqua D Vein	92·07	5 03	2 9	Moshanna Creek . . .	70·50	29·5	6·1
„ E Vein	89·2	4·54	6·26	Steed's Mine . . .	79·6	20·4	11·20
„ R Vein	87·45	7·55	5·10	Leech's Mine . . .	79·68	20·32	11·75
Fuscurora	88·2	7 5	4·3	Ralstan Lyconing Company . .	79·50	20·5	5·
Pottesville Schuyl Comp. Schenewith	94·1	1 4	4·5	Karthaus Upper Seam . .	87·	13·	8·80
Neeley's Tunnel	89·2	5 4	5 4	„ Lower Seam . .	75·2	24·8	4·70
Sharp Mountain P. G.	80·57	7 15	3·28	Reed's Six-Feet Vein Curwinsville .	73·	27·	5·30
Black Spring Gap . . .	82·47	9 53	8·00	Bear Creek	68·	32·	5·20
„ Lea Vein . .	85·84	8·96	5 20	Warner's Caledonia Three Feet .	61·8	38·2	7·20
„ Grey Vein . .	81·02	9 78	9 20	„ „ Five Feet .	63·	37·	8·5
Gold Mine Gap Pea. Vein . .	82 15	10·95	6·90	Blairsville	69·	31·	4·
„ Heister Vein . .	81·47	10 63	8·1	Sandy Ridge	56·8	43·2	7·
Yellow Spring Gap	79·55	10·95	9 50	Venango Company's Cannel . .	47·22	52·78	17·68
Ruttling Vein	74·55	15·75	11 70	Greersberg . . .	64·0	36·0	33·88
Big Flats	76·94	13·06	8·0	Coneant Lake . . .	61·25	38·75	1·8
Lyken's Valley	88·25	8 85	2 90	Greenville	59·5	40·5	1·7
Shamohin	89·90	6·10	4·	Orangeville	56·25	43·75	2·8
Wilkesbare Ward.	88 9	7·68	3.42	Snowshoe	78 8	21·2	2·07
„ „ Carbondale .	90·23	7·07	2 70				

Note.—All the varieties contain more or less of sulphur. In the anthracite running from ·48 to ·91 per cent. of the ashes and in the bituminous from 2·6 to 2·7 per cent. The general characteristics of each kind are for anthracite, ecomomy of space, freedom from smoke and cleanliness; for bituminous, free combustion, smokiness, and less durability than the anthracite.

The ratio of carbon in coals, it is thus seen, varies considerably; so also does the quantity of hydrogen. Generally, bituminous coals yield less carbon than anthracite coals, but more hydrogen. Bitumen renders coals easily ignited and smoky, whilst it gives them that caking quality so much appreciated for domestic use in London, by melting the coals together, thereby closing the top of the fire, and, by preventing the heat being so rapidly carried up the chimney, causes it to radiate more into the apartment. It also at the same time tends to prevent light ashes flying about, an evil so much complained of with less bituminous coals.

The waste of heat which takes place in ordinary fires, by about two-thirds of it passing up the chimney, is well known; yet how few fire-places are constructed otherwise than to increase this waste, or "draught," as it is called. A better class of radiating fire-places, at once elegant and economical, seems still to be a desideratum, where custom and prejudice hold so firm a sway as to prevent attention to either comfort or cost.

Dr. Arnott's experiments showed that full one-half the heat evolved was carried directly up the chimney; a large portion of that radiated outwards was immediately drawn back into the chimney, and only a small proportion of the whole into the apartment. Many of the open burning coals contain more carbon, and give out more heat by about 10 per cent. in steam-boiler furnaces than the Newcastle caking coals.

Anthracite contains more carbon than bituminous coals, is more clean, by burning nearly free from smoke, and is now variously used.

The following is the average range of variation in 100 lbs. of each fuel:

BITUMINOUS COALS.

Carbon . .	53 to 88	lbs. in every 100 lbs. of coals	
Volatile gases (nitrogen, oxygen, and hydrogen) .	44 to 10·5	lbs.	,,
Ashes . .	3 to 1·5		,,
Total	100 or 100		

ANTHRACITE.

Carbon . .	75 to 94	lbs. in every 100 lbs. of coals	
Volatile gases (nitrogen, oxygen, and hydrogen) . .	14 to 1·5	lbs.	,,
Ashes . .	11 to 4·5		,,
Total	100 or 100		

The coal tables supply a detailed analysis of each of the numerous varieties therein named.

Not only to coal-mine proprietors and engineers, but also to other coal consumers, will these tables be useful, either for comparison or selection in the railway-extended and extending field of choice and competition. For instance, London, besides its usual supply of "sea-borne" coals, now commands Newcastle, Yorkshire, and Derbyshire coals, cheaply supplied by the Great Northern Railway; the Lancashire coals by the London and North Western Railway; and will also shortly command, equally cheap, nearly all the tabulated varieties of the superior Welsh coals by the Great Western Railway.

These several sources of supply embrace coals of every

variety, and the tables supply the correct general character of each coal-field and of many individual sorts by name, which can scarcely fail to be useful to a wide circle, either directly interested in steam-engine or household consumption of coals.

It may be remarked, that for London alone, in 1848, 3,380,786 tons, and in 1849, 3,479,189 tons of coals, paid the city duty of 13*d.* per ton as brought within the Port-boundaries either by sea or inland conveyance; and that during the year ending last July, 271,066 tons of coals were exported from Liverpool, of which 143,037 tons were to the continent of America.

The coals in the following countries are thus approximately estimated:

	Area, Sq. Miles.	Tons dug in 1845.
In Great Britain:		
Bituminous . .	8139	31,500,000
Anthracite and culm	3720	
In the United States:		
Bituminous .	133,132	1,750,000
Anthracite . .	437	2,650,000
In France . .	1719	4,141,600
In Spain . . .	3408	
In Belgium . .	518	4,960,000
In Prussia . . .		3,500,000
In Austria . .		700,000

The quantity raised now in Great Britain is estimated as about 36 millions of tons, of which about 2 millions are exported, 8 millions consumed in iron-making, and $\frac{3}{4}$ of a million in making coal gas for general use.

In making coal gas for illumination, the quantity of hydrogen evolved varies from about 5000 to 11,800 cubic feet per ton of coals, and is thus estimated:

Scotch cannel . .	11,800 cubic feet of gas
Lancashire cannel . .	11,600 ,,
Newcastle . .	9,600 ,,
Staffordshire . .	6,400 ,,
Wallsend .	10,300 ,,
Templemain . .	6,200 ,,
Tenby . .	4,200 ,,

Besides lighting purposes, the heating power of gas is now drawing attention to its domestic economy. Mr. Defries raised the temperature of 45 gallons of water from 50° to 100° Fahr. by 30 cubic feet of gas, at a cost of $1\frac{1}{2}d.$ Mr. Evans estimates the heating power of 1 cubic foot of Newcastle coal gas as equal to boil off into steam 22 times its own weight of water, and practically boiled off from 12 to 13·6 times its own weight as below:

Gas burnt cubic ft.	WEIGHT OF GAS.		WATER BOILED.		Heating power. Ratio.
	Grs.	Spe. grav.	lbs.	Ratio to gas.	
1	206	·416	—	—	22
1	205	·413	·4	13·6	—
1	290	·564	·5	12·0	—
1	360	·700	·7	13·6	—

Evaporative Value of the Hydrogen in Coals.

It has been usual, as previously stated, to regard the heat given out by the combustion of hydrogen as little more than compensating for its production, and that by the quantity of carbon in any fuel its evaporative value was indicated. The following useful table shows the theoretical duty possible by 1 lb. of coals, by the coke in 1 lb. of coals, and by the hydrogen in 1 lb. of coals, with the total theoretical compared with the realized duty.

Table No. 30.

THEORETICAL AND PRACTICAL DUTY OF *1lb.* OF COALS, AND ITS CONSTITUENT PARTS.

NAME OF FUEL.	Water converted or convertible into Steam.					Force or power of 1 lb. of coals	
	Theoretically convertible						
	By 1 lb. of coal. Total.	From the hydrogen in 1 lb. of coals.	From the carbon in 1 lb. of coals.	Practically converted by 1 lb. of coals.	Theoretically convertible by the coke in 1 lb. of coals.	Equal to a weight raised 1 ft. high. Practical.	Is capable of raising 1 ft. high. Theoretical.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Graigola . . .	13·563	1·903	11·660	9·35	11·301	7·060·908	10·242·471
Anthracite { Jones, Aubrey, & Co. }	14·593	2·030	12·563	9·46	12·554	7·143·978	11·020·303
Oldcastle Fiery Vien .	14·936	2·890	12·046	8·94	10·601	6·751·285	11·279·329
Ward's Fiery Vien .	14·614	2·542	12·072	9·40	...	7·098·667	11·036·162
Binea	15·093	2·912	12·181	9·94	11·560	7·506·463	11·397·89[illegible]
Llangenock . .	14·260	2·519	11·741	8·86	10·599	6·690·871	10·768·829
Pentripoth . .	14·838	2·649	12·189	8·72	10·873	6·585·146	11·205·322
Pentrefellin . .	13·787	2·038	11·749	6·36	10·841	4·802·928	10·411·630
Powell's Duffryn .	15·092	2·966	12·126	10·149	11·831	7·664·295	11·397 137
Mynydd Newydd .	14·904	3·441	11·463	9·52	9·831	7·189·288	11·255·163
Three-quarter Rock Vein . . . }	13·106	2·781	10·325	8·84	7·081	6·675·768	9·897·355
Cwm Frood Rock Vein	14·788	3·488	11·300	8·70	8·628	6·570·043	11·167·563
Cwm Nanty Gros .	13·932	3·165	10·767	8·42	8·243	6·358·593	10 521·131
Resolven . . .	13·971	3·072	10·899	9·53	10·234	7·196·840	10·550·583
Pontypool . . .	14·295	3·207	11·088	7·47	8·144	5·641·175	10·795·260
Bedwas . . .	14·841	3·766	11·075	9 79	8·879	7·393·186	11·207·587
Ebbw Vale . . .	15·635	3·300	12·335	10·21	10·441	7·710·361	11·025·198
Porthmawr Rock Vein	12·811	2·548	10·263	7·53	6·647	5·686·485	9·674·577
Coleshill . . .	12·799	2·654	10·145	8·0	6·468	6·041·419	9·665·515
Dalkeith Jewel Seam	12·313	2·071	10·242	7·08	6·239	5·346·655	9·298·499
Dalkeith Coronation .	12·772	2·202	10·570	7·71	6·924	5 822·417	9·645·125
Wallsend Elgin . .	13·422	2·968	10·454	8·46	6·560	6·388·800	10·135·991
Fordel Splint . .	13·817	2·884	10·933	7·56	6·560	5·709·141	10·434·286
Grangemouth . .	13·692	2·722	10·970	7·40	7·292	5·588·312	10·339·888
Broomhill . . .	14·863	3·638	11·225	7·30	7·711	5·512·795	11·224·201
Park End, Lydney .	13·257	3·156	10·101	8·52	6·567	6·434·111	10·011·386
Slievardagh (Irish) .	12·482	1·487	10·995	9·85	10·895	7·438·497	9·426·124
Formosa Island . .	13·553	2·801	10·752	...	...	...	10·234·919
Borneo (Labuan kind)	10·252	1·388	8·864	...	...	...	7·742·078
" 3-feet seam .	8·756	1·295	7·461	...	...	...	6·612·333
" 11 " . .	11·600	1·948	9·652	...	...	...	8·760·057
Wylam's Patent Fuel	14·331	3·145	11·186	8·92	8·378	6·736 182	10·822·447
Warlich's . . .	15·964	3·596	12·368	10·36	11·292	7·823·637	12·955·652
Bell's	15·417	3·343	12·074	8·53	9·168	6·441·663	11·642 569

The respective evaporative values are estimated by taking 13268 as the unit of heat in a pound of carbon, and 62470 as the unit of heat in a pound of hydrogen, and dividing by the vaporization heat of 965·7°. The coke value is obtained by subtracting from it the quantity of ashes due to the coals, and considering the remainder as carbon.

By this table it is observed that although there are striking exceptions, the work capable of being done by the coke alone is greater generally than that obtained from the coal.

A closer examination of the experiment at the Par Consols mine appears, however, to indicate that the hydrogen does exercise a beneficial result on the evaporative powers of the fuel. The quantity of water evaporated was 11·428 lbs. by 1 lb. of coals, and their composition was 84·19 of carbon, 4·19 of hydrogen, 86 of oxygen, 8 of nitrogen, 1·9 of sulphur, and 8·06 of ashes. The water being at 212° temperature required only 965·7° of heat to convert it into steam. Taking Dulong's values of 13268° of heat for carbon, and 62470° of heat for hydrogen, in this instance, we can readily compare the theoretical with the practical effect.

Theoretically we have,

$$\text{Carbon} = \frac{84{\cdot}19 \times 13268}{100 \text{ lbs.} \times 965{\cdot}7} = 11{\cdot}567 \text{ lbs. of water,}$$

$$\text{and for hydrogen} = \frac{4{\cdot}19 \times 62470}{100 \text{ lbs.} \times 965{\cdot}7} = \underline{2{\cdot}71} \text{ lbs. of water,}$$

total theoretical value of 1 lb. of coals = 14·267 or

$$\begin{aligned} \text{together,}\quad \text{carbon} &= 84{\cdot}19 \times 13268 = 1117032{\cdot}92 \\ \text{hydrogen} &= 4{\cdot}19 \times 62470 = \underline{261749{\cdot}30} \\ & \qquad\qquad\qquad\quad 1378782{\cdot}22 \end{aligned}$$

as the units of heat in 100 lbs. of coals, which being divided by the evaporative heat of 965·7° × 100 lbs. of coals = 14·277 lbs. of water, capable of being evaporated by 1 lb. of these coals.

Practically, 1 lb. of coals evaporated 11·428 lbs. of water from 212°, or only ·139 lbs. less than the theoretical value of carbon, but this 11·428 lbs. was not all the heat actually obtained from the fuel. For it is stated that by an arrangement of water-pipes in the flues, the feed-water was heated to about 212°, by the heat absorbed from the passing gases on their way to the chimney, where their temperature was still 300°. Taking the ordinary temperature of water as 52°, it requires to absorb 160° to raise it to 212°, hence the actual evaporation of $\frac{10·204 \times 160}{965·7} = 1·690$ lbs. of additional evaporative heat from the coals, making 11·894 lbs. as the total heat absorbed, or ·327 lbs. more than was possible by the carbon, and 2·37 less than the total theoretic value of 1 lb. of coals. Without considering the 300° of heat still left to escape up the chimney, the beneficial effect of the hydrogen in the evaporative results is quite evident.

The Mynydd Newydd coals having a similar large proportion of hydrogen (4·28 per cent.), it will be seen by the table that they have a higher practical value than several others possessing more carbon, but less hydrogen.

Taking as another example the Aberaman Merthyr coal, containing 90·94 per cent. of carbon, and 4·28 of hydrogen, possessing the highest evaporative value in these tables, or 10·75 lbs. under the experimental boiler:

For the Cornish boiler the evaporation would be

$10·75 \times 1·1995 = 12·894$ lbs., and as before,

Carbon $90·94 \times 13268 = 1206591·92$, or 12·494 lbs.
Hydrogen $4·28 \times 62470 = 267371·60$, or 2·769 lbs.

$\frac{1473963·52}{100 \times 965·7} = 15·263$ lbs. as the theoretic value of 1 lb. of these coals.

Taking the absorption of carried heat by the feed-water to

be, as before, equal to 160° for the quantity evaporated, we have $\frac{10{\cdot}75 \times 160}{965{\cdot}7} = 1{\cdot}781$ lbs. as its value,

and $10{\cdot}75 + 1{\cdot}781 = 12{\cdot}531$ lbs. or ·037 more effect from an inferior boiler than due to the carbon.

If the heating values assigned to carbon and hydrogen be correct, it is very gratifying to find so fair an approximation of practice to theory.

These examples from experiments made by a Government officer for official purposes only, clearly indicate that the gases evolved during combustion do exercise a beneficial effect in generating steam. Since a deficiency of hydrogen may be made up to some extent by introducing water, it is a reasonable deduction, that the practice we have before referred to is consistent with theory.

The last two columns of the table show the practical, mechanical, and theoretical value of 1 lb. of the respective fuels. It is based on Mr. Joule's estimate, that the mechanical value of air and of heat equal to raise 1 lb. of water 1° Fah., is 782 lbs. The application is simply by multiplying the number of pounds of water evaporated by the heat of evaporization, in these cases 965·7° and by 782 for the total value. It is, however, right to state that others take only 682 as the mechanical equivalent of an unit of heat.

Taking the Mynydd Newydd as an example, whose practical value is 9·52 lbs., it gives $9{\cdot}52 \times 965{\cdot}7 \times 782 = 7{,}189{,}288$ lbs., raised 1 foot high. The theoretical value is obtained in a similar manner by taking the ratio of 9·831, instead of 9·52.

Heating of the Feed-water.

It is not unusual to find a very high value placed upon this practice, by those who have not fully investigated the matter. The last two examples show that in the one case it added 1·69, and in the second case 1·78 lbs. to the evaporative value of the

fuel, when the water was heated to 212°. The mistake arises from supposing that only 212° of heat are required to evaporate steam of atmospheric pressure, whilst by Regnault's careful experiments it requires 965·7° + 212 = 1177·7°. From this is to be deducted the initial temperature of the water, which if taken at 52° leaves 1125·7° to be imparted in order to convert that water into steam. Hence,

$$\frac{1125{\cdot}7}{212-52} = 7{\cdot}04 \text{ or } 14{\cdot}19 \text{ per cent.}$$

as the utmost gain. If less than the boiling temperature is attained by such heating then the gain would be proportionally decreased, as shown in the following table :—

TABLE No. 31.

Ratio of the Heat applied to Feed-water to the total Heat of Steam of Atmospheric Pressure, or 1177·7° *less the Initial Heat of the Water, or say* 52° *Temperature* = 1125·70.

Water heated from 52° to Fah.	Increase in deg. Fah.	Increase per cent. of the heat of Steam.
62	10	·887
72	20	1·77
82	30	2·66
92	40	3·54
102	50	4·43
112	60	5·32
122	70	6·20
132	80	7·09
142	90	7·98
152	100	8·87
162	110	9·75
172	120	10·64
182	130	11·53
192	140	12·41
202	150	13·30
212	160	14·19

SECTION II.

CHAPTER I.

VARIETIES OF STEAM.

In its general acceptation, steam is pure water expanded by heat into an invisible vapour, but as water is rarely found pure, the heat which distils it into steam also deposits these impurities. Under the influence of solar heat these deposits are familiar in the immense deltas constantly forming at the mouths of rivers; and under the influence of ordinary heat, they are familiar in the "fur" deposited in tea kettles, and incrustations in steam boilers.

There are several distinct varieties of steam recognised, of which we may enumerate,

I. Natural steam, raised by solar heat.

II. Spheroidal steam, raised by dropping water on hot metallic surfaces.

III. Surcharged steam, raised by heating common steam when not in contact with water.

IV. Common steam, raised by ordinary heat.

Natural Steam.

Natural steam is that raised from the various accumulations of water on the earth by solar heat, and is believed to be perfectly analogous to common steam. In a fine day, when solar heat raises natural steam most abundantly it is invisible, so likewise with steam generated in a glass bottle over a spirit lamp, until it comes in contact with the atmosphere. Partial condensation then occurs, and it becomes visible in the form of light fleecy clouds. When the atmosphere is saturated with natural steam, a partial condensation begins to operate, and natural steam becomes visible in the form of clouds, whilst its descent in the shape of mist or rain attests its abundance.

Common steam also assists us to arrive at the probable cause of the beautiful colours which occasionally adorn the floating clouds to the delight of the spectator.

Professor Forbes, having accidentally observed that the steam issuing from a locomotive safety valve changed colour when seen between the observer and the sun, made a series of experiments on the subject at Glasgow, in 1839, which confirmed his accidental discovery. He first observed that at the immediate edge of the safety valve the issuing steam was invisible, but at a short distance from the edge of the valve it had a red appearance, similar to looking at the sun through smoked glass, or the smoky atmosphere common to large cities in peculiar states of the atmosphere. This redness gradually faded away until the steam resembled the ordinary clouds.

The experiments confirmed the original observation, and led him to conclude, that, to the rays of solar light passing through natural steam in a state of partial condensation, were due the gorgeous colouring of the clouds pleasingly adorning our evening skies, and frequently calling forth the artist's skill in delineating "sunset."

The stupendous operations performed by the Great Creator with natural steam have long arrested the scrutinizing attention of philosophers, geologists, and meteorologists, and are thus referred to by the celebrated musician Haydn, in his Oratorio of the Creation, as among the leading phenomena of nature—

> "Now from the floods the STEAMS ascend to form reviving showers,
> The desolating hail, the light, the fleecy snow.
>
> *　　*　　*　　*　　*
>
> Ye mighty elements, by whose power
> Are ceaseless changes made:
> Ye mists and vapours that now rise
> From hill or STEAMING lake."

The mighty influence, therefore, of solar heat in raising

steam from rivers, lakes, and oceans, to be condensed by the cold of the upper regions, and return to the earth again in rain, hail, or snow, becomes obvious in the succession of atmospheric changes.

Natural evaporation is also greatly influenced by the motion of the air, as shown in the following experimental table by Dalton, giving the evaporation from a vessel 6 inches in diameter, exposed to the atmosphere.

TABLE No. 32.

RATE OF NATURAL EVAPORATION OF WATER.

Temp.	In. Mer.	Calm. Grains.	Gentle Breeze. Grains.	Brisk Wind. Grains.
40	·263	1·05	1·35	1·65
42	·283	1·13	1·45	1·78
44	·305	1·22	1·57	1·92
46	·327	1·31	1·68	2·06
48	·351	1·40	1·80	2·20
50	·375	1·50	1·92	2·36
52	·401	1·60	2·06	2·51
54	·429	1·71	2·20	2·69
56	·458	1·83	2·35	2·83
58	·490	1·96	2·52	3·08
60	·524	2·10	2·70	3·30

Ordinary evaporation is also increased by the quantity of vapour in the air, which increase may be thus determined: Ascertain the dew point, or that temperature when the vapour in the air will begin to condense on a colder body, such as a glass containing a cooling mixture. As soon as this dew or condensing point of the natural steam in the air is found, say at 42°, and the temperature of the air at rest is 58°, the natural steam in the air would be 1·96 by the table, from which

deduct the vapour for the dew point of 42° = 1·13, leaving ·83 grains per minute as the ratio of evaporation from a surface of very nearly 29 square inches. The following is one of Daniell's experiments on this point:

The temperature of a room was 45° and the dew point 39°, when a fire was lighted until the temperature rose to 55°, but the dew point remained the same. A party of eight persons then occupied the room for several hours with the fire kept up, when the temperature rose to 58° and the dew point to 52°, hence a considerable accumulation of vapour had taken place, which should have been carried off if the apartment had been properly ventilated. By these simple means the relative states of the air of a room may be ascertained and improved.

Some definite idea will be formed of the magnitude of natural evaporation when it is considered that it must necessarily be equal to the total supplies of water from all sources, or otherwise another deluge would result from a lesser evaporation.

The Mississippi is estimated to supply 1,110,600 millions of cubic feet of water annually, and to deposit unevaporable matter equal to $\frac{1}{3000}$ of its volume, or 3702 millions of cubic feet. The Ganges is estimated to deposit unevaporable matter equal to 6,000,000 cubic feet, or 355,000,000 of tons annually. Other rivers and streams are also daily carrying the crust of the present earth to the ocean, in greater or lesser quantities, leading to the opinion that in the lapse of time the present relative position of dry land and water will be changed, when the Bucklands, the Lyells, and the Mantells of other ages will be investigating the geological character of the present deposits. That this idea is not without a reasonable basis may be inferred, since the existing delta and plain formed by the deposit of the Mississippi forms an area of 31,200 square miles, or nearly as large as Ireland, which contains 32,512 square miles of surface.

Such is an outline of nature's operations with steam, com-

pared to which the greatest efforts of man—however considerable in his sphere—are small indeed, but the vast difference is not more striking than instructive to mankind.

Spheroidal Steam.

About 1844 this variety of steam was introduced in France by M. Boutigny, and brought into practice by M. Beauregard, who patented its use in this country in 1848. Although it is not probable that it will come in competition with ordinary steam, either for economy or usefulness, considerable notice was taken of it at the time. It is produced by dropping water in a red-hot metal plate, having an indented surface to prevent its running off the plate. When the water is about 206° temperature it adheres to the plate, and slowly passes off into steam; it is said of the elasticity due to the temperature of the plate, and not of the water, and this difference of elasticity is the source of the economy claimed by M. Beauregard for his spheroidal steam generators. When the water is of a higher temperature than about 206°, the repellent power of the heat of the plate and sphere of water prevent their contact, and, as may have been seen when a drop of water has fallen on a hot plate, it runs about growing less and less until it disappears altogether, without being converted into steam. It was estimated that by this generator the water passed into steam about fifty times slower than by an ordinary boiler, but possessing a force which requires only about one per cent. of the space. The spheroidal generator was tried with a vessel of melted lead, heated to 540°, having a hemispherically indented platinum bottom plate, on which the water was thrown from a suitable pipe. The results were said to be more economical than with ordinary steam, but this may reasonably be doubted, since it is the real economy of ordinary steam which enables and will still enable it to compete with many ingenious productions of motive power, where greater expense prevents their

realization in practice. Carbonic-acid gas, air, and other motive agents, can and have been found to be capable of developing great power, but have failed as yet to be so economical as steam, and have fallen into disuse from that cause.

Heated Steam or Stame.

More recently Mr. Frost, of America, has called attention to the much greater economy of steam when heated between the boiler and cylinder, than when used in the ordinary way. This heated steam he calls "stame," and contends that it is a different vapour produced by different atomic proportions of heat and water than form ordinary steam. Like M. Beauregard he also estimates the comparative economy as about 4 to 1 in favour of stame. A short description of his instructive experiments may lead to their further investigation.

Fig. 25. *Fig.* 26. *Fig.* 27.

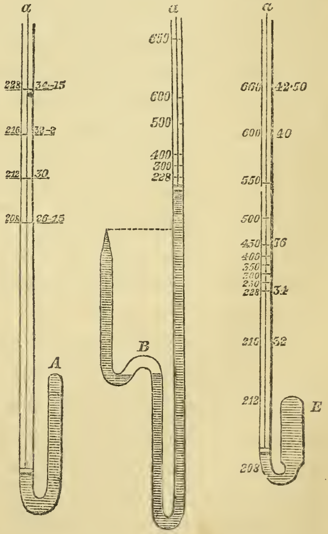


Fig. No. 25 is a bent glass tube closed at the short end, which contains one drop of water at A. Mercury is then admitted to fill the short end, and a part of the long end of the tube containing a float and index, *a*. The pressure on the drop of water was, therefore, the atmosphere and the mercury in the tube. After being carefully prepared, this eudiometer was placed in cold water, which was gradually made to boil at 212°, and then slowly saturated with salt till the boiling point was stationary at 228°; the ex-

pansion being marked, as seen in the diagram at the respective temperatures of the two boiling points.

Fig. No. 26 is a tube of a different form, where the drop of water was confined at the bend B, between two columns of mercury. The short end was closed, and the long end open. It was then subjected as before to boiling at 228° to determine that volume, and then transferred to a mercurical bath, which was gradually heated to 650°. The float and index marked the volume and the pressure in inches of mercury, whilst a thermometer marked the temperature of the bath as it slowly cooled down again. These were carefully noted, and showed much irregularity in the rate of expansion, as marked in the diagram.

Fig. No. 27 is a repetition of the same experiment in a different tube, having a drop of water at the extremity of the bulbous end E. The expansion was carefully marked at 212° to obtain the atmospheric volume, and it was then transferred to the bath as before, when the cooling showed a similar irregularity of expansion as the former experiment. These experiments show the rate of expansion of steam in contact with mercury from 212° to 650°, but not in contact with any water. Similar experiments were performed with the same tubes, but using fusible metal and linseed oil to confine the steam, when the rate of expansion was much more uniform, while nearly the same at the extreme pressures. Taking the difference in the specific gravities of the mercury, fusible metal and oil, the extreme differences may be considered as due to the difference of pressures.

From these experiments it appears that the mercury exercised an influence on the rate of expansion by equal increments of heat, not done by the metal or oil. But what more particularly requires to be noticed and further tested is the great increase of volume by increase of heat, with a slow increase of elastic force. For whilst the elastic force only increased 12·5 inches of mercury, the volume was increased to

seven times that of 212°, making a total volume eight times greater than the atmospheric volume of ordinary steam.

It has been usual to treat steam as subject to the same laws as air, which expands ·00202, or $\frac{1}{480}$ of its volume for each increase of one degree of Fahr., but these experiments show an increase of seven volumes for an increase of only 438° of heat.

If further carefully conducted experiments confirm these results, then Gay Lussac's law for permanent gases is not adapted for heated or surcharged steam. As that law purports to commence at 32° when the volume of water is 1, which at 212° becomes suddenly 1700 times that volume, Gay Lussac's law has been applied to steam, through the 1700 volume, and correction of 180° temperature, so that its failure in steam—if failure it prove, may not affect its application to permanent gases, for which it was submitted. The probability that the variation in the respective states of water at 32°, 40°, and 212°, known as ice, water and steam, may in stame not perhaps be governed by a law designed for permanent gases, cannot be remarked without reflections on the Author of that law.

Fig. 28.

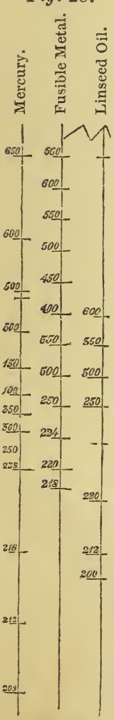
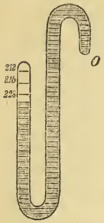


Diagram No. 28 shows the results of these experiments collected on a scale of equal parts. The metal was bismuth 5, lead 3, and tin 2, which is fusible at 210°, but on cooling it lost its fluidity so far at 218° as not to be depended upon below that temperature.

To test in another way the influence of the pressure of bodies on the generation of steam, when in contact with these bodies, the following experiments were tried:

The glass eudiometer, Fig. 29, was filled with boiling water and heated in a bath at 650°, when all the water was expelled, and its open end *o* her-

Fig. 29.



metically sealed, leaving only the water due to the steam in the tube. This being condensed, left a vacuum, and the tube being immersed in a vessel of mercury, the sealed end was broken off, when of course the mercury instantly filled the vacuum. On being subjected to heat, the steam showed itself at the usual temperatures. The same process was repeated with turpentine, but up to its boiling point of 316° no steam appeared. Also with linseed oil, no steam showed itself up to 400° temperature.

These experiments indicate that whilst mercury exercises no great influence over minute portions of water passing into steam, yet both turpentine and linseed oil do so to a great extent. The fixity of water when subjected to high temperatures, as exemplified in the spheroidal generator, was tested by introducing a small drop of water about one inch below the surface of the linseed oil, with which water does not combine. The glass tube was then slowly heated to 300° but the water remained unevaporated. At 320° it began to decrepitate, and at 340° the concussions led to the close of the experiment to save the tube from being broken, when one-half of the drop of water still remained. Since linseed oil is lighter than water, as ·93 to 1, the pressure was less than that of an equal column of water, through which steam rises with rapidity, yet the temperature was equal to that of ordinary steam at 116 lbs. per square inch. To test the results of these experiments practically, two engines, one having a three-inch, and the other a six-inch piston, giving the respective areas as one to four, were tried publicly, and showed a corresponding gain in favour of *stame* over *steam*. They were both supplied with steam from the same boiler, generated by equal quantities of fuel, consumed in equal times. The only difference was, that the steam pipe to the large cylinder was carried through the upper part of the furnace in a spiral tube, having a heating

area of about $\frac{1}{5}$ that of the boiler. Measured by one of Morin's Dynameters the power given out was four times greater from the larger than from the smaller cylinder, indicating that the pressure on both cylinders was nearly alike, and that the increase *of volume* was due to the heat taken up by the steam in passing through the furnace. If this is a fair estimate of the difference, it shows that there is a considerable gain at a small cost; and that of the theoretical expansion of eight volumes, four were realized in practice, whilst the remainder filled the extra pipes and balanced the abstraction of heat again by colder bodies and other resistances.

Mr. Frost gives the following comparison of steam and stame, with the effects of the exhausted steam, in baking bread from dough:

Pressure.		Temperature in			Effects on Dough.	
—	Atmos.	Boiler.	Cylinder.	Exhaust pipe.	Surface.	Substance.
Steam	6·5	321°		216°	Glistening.	Tender.
Stame	2·5	264°	612°	550°	Charred.	Hard.

This is probably an extreme result, giving 612—550, a loss of only 62°. For stame is found to take up and part with heat rapidly to colder bodies, requiring the temperature of the conducting pipe and cylinder to be maintained when the heated steam was six times as effective as ordinary steam, although passed through a coil of piping ten times the length of the ordinary steam pipe.

From experiments made in France, it is stated that steam heated to 392° does not char wood, that at 482° it is imperfectly charred, at 572° it is charred brown, and at 662° it makes black charcoal, yielding a greater quantity and better quality of charcoal for making gunpowder than by the ordinary process of charring.

The French Minister of War advanced 5000 francs for carrying out these experiments, which led to its adoption

for making the charcoal at the Esquinede gunpowder mills. The experiments were made similarly to M. Frost's, by heating ordinary steam in a coil of pipe 8 inches diameter, and 66 feet long. M. Violette states, that at 392° bread can be baked, meat cooked, and other extractive operations successfully accomplished by stame, for we prefer the more simple name to any compound of surcharged, heated, or anhydrous steam, by all of which names it is occasionally designated.

At Stonehouse, Plymouth, Mr. Lee's patent oven is said to bake superior bread in an atmosphere of stame whose heat is regulated by a thermometer. To numerous visitors of the Crystal Palace, Mr. Perkins, of London, distributed pieces of bread baked in his patent "hot water" or stame oven, by the radiation of the heat through coils of pipes forming shelves for the loaves.

The importance of stame is, therefore, not confined to its operations in the steam engine, but extends over a wider field. In America, Frost's experiments drew the attention of the Institute of Arts and Sciences at New York, who give the following tabular results of experiments: The steam was got up to 21 lbs. pressure, and the engine made 2000 revolutions, which exhausted the steam in the boiler, and the condensed steam raised the temperature of the condensing water from 48° to 62°, or 14°. With the same pressure in the boiler, but heated in passing to the cylinders, when the engine had made 2000 revolutions by stame the pressure in the boiler was raised to 37 lbs., and the water in the condenser from 61° to 70°, or 9°. During the trials the condenser showed a steady vacuum of 12 lbs. For equal volumes, therefore, it appears that the heat was greater in steam than in stame in the ratio of the heat communicated to the condenser, or as 14 to 9; and that the less abstraction of heat from the boiler by stame, added the difference between 21 and 37, or 16 lbs. effective pressure to the steam in the boiler, whilst with ordinary steam the heat was all expended and could not sustain the pressure.

Table No. 33.

EXPERIMENTS ON STAME BY THE COMMITTEE OF THE ARTS AND SCIENCES INSTITUTE, NEW YORK.

At Low Pressure.

Temp. Fah.	Vol. In. mer.	Pressure. In. mer.	Actual volume of stame each.
31	0·1	0·2	0·1
94	1·	2	2·
115	2	4	8
128	3	6	18
138	4	8	32
150	5	10	50
159	6	12	72
165	7	14	98
172	8	16	128
180	9	18	162
212	10	20	200

At High Pressure.

Temp. Fah.	Vol.	In. mer.	Pressure.	
			Atmospheric.	In a given vol. In. mer.
212	1	30	1	30
216	2	32	2·133	64
228	3	34	3·4	102
450	4	36	4·8	144
600	6	40	7·2	216
650	7·37	42·75	9·8	294

The committee felt satisfied of the importance of these experiments, and of the economy of stame if it could be brought into operation, where the temperature of colder bodies would not interfere to abstract the heat before it could be profitably employed.

Dr. Haycraft, of Greenwich, had also made a number of experiments with stame, or, as he designates it, anhydrous steam, and freely criticized Frost's mode of conducting his experiments as liable to error, at the same time giving instances where he had himself been deceived in the results of practice, as compared with the results of experiments. He tried his plan on an engine having a 9-inch cylinder, and 3-feet stroke, which worked very economically, but he found that the pipes subjected to the heat gave way, and in the aggregate did not realize what he expected. He then employed a steam jacket, and a vessel for separating the steam from any unevaporated water, and realized in a large engine 25 per cent. by the separation, and 46 per cent. economy where both steam jacket and separation were used. These experiments were made before Mr. Wright, the Government Comptroller and Inspector of Steam Machinery. Although Dr. Haycraft differs with Frost on some of the details of the experiments, he yet fully admits the economy of stame to be very nearly as great as it is estimated by Frost.

The ease with which stame could be tested fully in inside cylinder locomotives, and its admitted economy, have led us to give this abstract of Frost's experiments, and the opinions of those who have criticized them, as a subject capable of further investigation at a nominal cost. A coiled steam-pipe in the smoke-box end, where the temperature of the escaping gases is always high, would soon indicate its value in locomotive engines, where, if successful, a further reduction in the quantity of fuel consumed would be effected.

CHAPTER II.

Common Steam.

By combining heat and water together in a close vessel steam is produced, and as a well-known elastic motive agent it has become quite a household word. To the hardy miner

in developing the treasures of the earth, to the skilful manufacturer in giving form to his fabrics, to the adventurous mariner in traversing the ocean, and to the traveller in rivalling the eagle's speed, steam has alike lent its potent aid, and now displays its agents and its triumphs in the Crystal Palace.

Thus to the fullest extent has been realized the prediction of Sir Samuel Morland in 1682, that steam might be harnessed to duty like a quiet horse. Even in the field of locomotion, where the muscular energies of that noble animal seemed to defy mechanical competitors, steam has won some of its greatest triumphs, and extended its usefulness.

The following properties of steam now claim our attention:

I. Its Elastic Force.
II. Its Mechanical Force.
III. Its Temperature.
IV. Its Volume.
V. Its Velocity.
VI. Its Expansive Force.
VII. Its Practical Force.

1*st. Elastic Force of Steam.*

An elastic body is one which presses equally in every direction, whilst admitting of being compressed into a smaller or expanded into a larger space, with the power of returning to its original space when restored to its original conditions again. Water, it has been seen, is almost incompressible, and is therefore a non-elastic body. Air, it has been shown, is compressible, and consequently is an elastic body. As water is made the standard of the specific gravities or weights of heavy bodies, so is air made the standard for gaseous elastic bodies, and its laws are usually applied to illustrate the elasticity of steam in contact with water. Besides possessing elastic properties similar to air, steam possesses the additional and valuable one of being easily condensed by cold to water again. In applying the acknowledged

laws of air to steam, they only apply when the steam receives its heat from the water and remains in contact with it, maintaining the given temperature increased or diminished only by the space it occupies. The numerous indicator cards taken from cylinders show that these laws are nearly correct for low-pressure steam; but that for high-pressure steam the curve of expansion is fuller than the theoretical or hyberbolic curve, indicating a greater continuation of force from a less rapid abstraction of heat than is assigned by these laws. Where locomotive engines have inside cylinders fixed in the hot-smoke box, this fuller curve is probably due to the high temperature imparting a slightly stame character to the isolated steam, but influenced by the velocity of the piston and heat on the smoke box. For all ordinary pressures and temperatures of steam in contact with water, the following laws of elastic fluids will practically explain the expansive property of steam. We find, however, that these laws and the practical application of steam to railway locomotion must be deferred to the Second Part, where they will be illustrated and fully explained in a popular manner.

32. Rudimentary Art of Use of Instruments (generally), by J. F. Heather, M.A., of the Royal Mil. Acad., Woolwich, 2nd edit. . 1s.
33. ——————— Constructing Cranes for the Erection of Buildings and for Hoisting Goods, by J. Glynn, F.R.S., C.E. . . 1s.
34. ————— Treatise on the Steam Engine, by Dr. Lardner. (*Written specially for this Rudimentary Series.*) . . . . 1s.
35. ————— Art of Blasting Rocks and Quarrying, and on Stone, by Lieut.-Gen. Sir John Burgoyne, K.C.B., R.E., &c. &c. . 1s.
36. ————— Dictionary of Terms used by Architects, Builders, Civil and Mechanical Engineers, Surveyors, Artists, Ship-builders, &c. vol. i. . . . . 1s.
37. ——————— vol. ii. . . . . 1s.
38. ——————— vol. iii. . . . . 1s.
39. ——————— vol. iv. . . . . 1s.
40. ————— Art of Painting on Glass, or Glass-Staining, by Dr. M. A. Gessert, with an Appendix on the Art of Enamelling, &c. 1s.
41. ————— Essay on the Art of Painting on Glass, by E. O. Fromberg 1s.
42. ————— Treatise on Cottage Building; and some new Hints for Improving Dwellings, by C. B. Allen, Architect . . . 1s.
43. ————————— Tubular, Girder Bridges, and others, more particularly describing the Britannia and Conway Bridges, with the Experiments made to determine their form, strength, and efficiency, by G. D. Dempsey, C.E. . . 1s.
44. ————————— Foundations and Concrete Works, by E. Dobson, C.E. . . . . 1s.
45. ————————— Limes, Cements, Mortars, Concrete, Mastics, Plastering, &c., by Geo. R. Burnell, C.E. . . . 1s.
46. ————————— the Art of Constructing and Repairing Common Roads, by H. Law, C.E. . . . . 1s.
47. ————————— the History, Construction, and Illumination of Lighthouses, by Alan Stevenson, LL. B., F. R. S. E., M. Inst. C.E. . . . . vol. i. 1s.
48. ————————— Ditto, Continuation of the same subject, vol. ii. 1s.
49. ————————————————————— vol. iii. 1s.
50. ————————— the Law of Contracts for Works and Services, by David Gibbons, Esq. . . . . 1s.
51. ————————— Naval Architecture, the Elementary Principles of the Science, by J. Peake, H. M. Naval Architect . . 1s.
52. ————————— the Practical Principles of Ditto, forming a 2nd and a 3rd volume, to complete the work, vol. i. . . 1s.
53. ——————————————————— vol. ii. . . 1s.
54. ————————— Masting, Mast-making, and Rigging of Ships . 1s.
55. ————————— Navigation: the Sailor's Sea-Book; in two Parts: I. How to keep the log and work it off. II. On finding the latitude and longitude. By James Greenwood, Esq., B.A.—With Directions for Great Circle Sailing; an Essay on the Law of Storms and Variable Winds; and an Explanation of Terms used in Ship-Building, with coloured illustrations of Flags, vol. i. . 1s.

56. Rudimentary Treatise on Navigation, &c., vol. ii. . . . . . . 1*s.*
57. ———————— the Principles of the Art of Warming and Ventilating Domestic and Public Buildings, Mines, Lighthouses, Ships, &c., by Chas. Tomlinson, vol. i. . . 1*s.*
58. ———————————————— vol. ii. . . 1*s.*
59. ———————— Steam Boilers, their Construction and Practical Management, by Robert Armstrong, C.E. . . . 1*s.*
60. ———————— Land and Engineering Surveying, for the use of Schools and Private Students; for Practical Land Surveyors, and Engineers, by T. Baker, C.E., vol. i. . 1*s.*
61. ———————————————— vol. ii. . 1*s.*
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